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# Integrated Catch at Age Analysis Version 1.2

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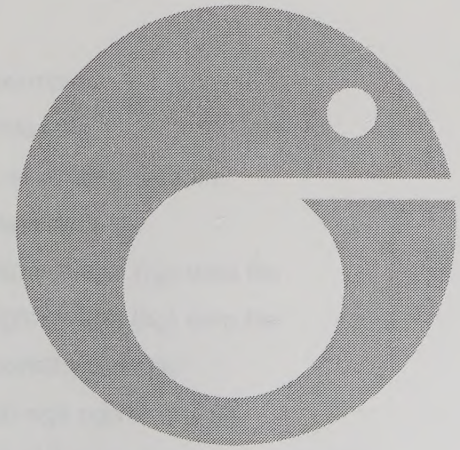

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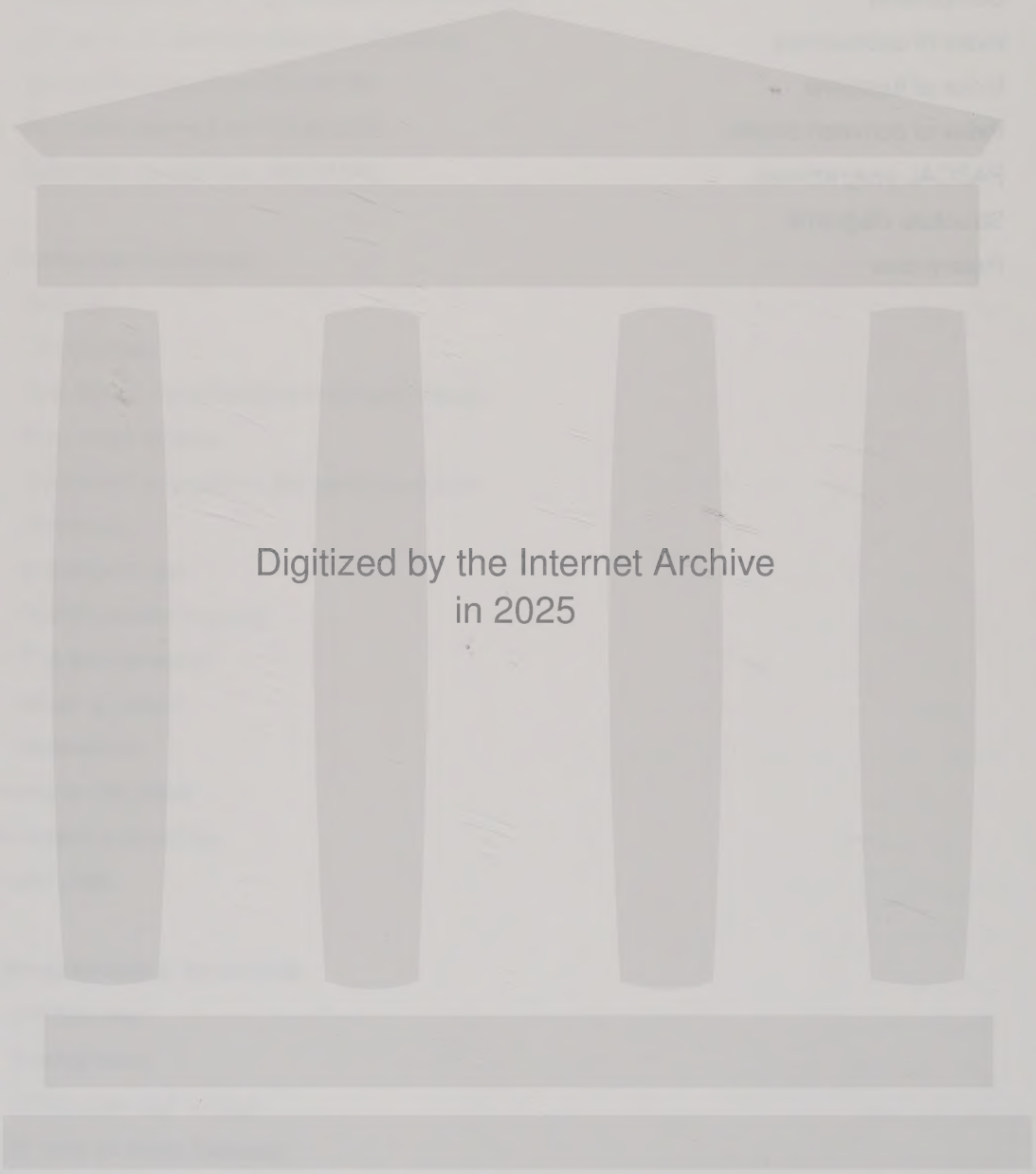

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# Integrated Catch at Age Analysis Version 1.2

K R Patterson[1] and G D Melvin[2]

## *Section A. User's Guide*

### 1.0 Overview and Purpose

This users' manual is a guide to the practical aspects of installing and running the "Integrated Catch at Age Analysis" programmes. Theoretical and statistical aspects are not covered here, and the prospective users are strongly urged to familiarise themselves with the formal background of the analytic model, which is described in the Technical Reference, and with the literature quoted therein.

The software package named "Integrated Catch-Age Analysis" (ICA) has been written to provide an analytical stock assessment tool which allows a variety of model choices to be implemented conveniently. A full implementation of the model would be extremely difficult to use on account of the flexibility of the method, and hence of the many user choices that would need to be made in running the programme. Consequently an implementation has been written that makes usable the desired features in a convenient fashion, while restricting alternative choices that are not relevant to the pelagic fisheries problem. The main features allowed are:

a) Tuning using either or both age-structured and spawning biomass (non-age structured) indices.

b) Choice of catchability model: identity, linear or power.

c) Inclusion of separable constraint.

d) Choice of series reweighting: equal, inverse-variance or fixed.

e) Inclusion of a Beverton and Holt stock-recruit relationship.

f) Calculation of a "shrunk" VPA based on the model fit.

The programme allows a statistical analysis of an age-structured data set to be completed simply and relatively quickly, so that the uncertainties inherent in a stock assessment can be assessed and the consistency of an assessment evaluated. It allows estimates to be calculated of the standard deviation of the estimated fishing mortalities, and of other parameters of management interest. A post-processing programme displays a series of graphs of the parameter estimates: fishing mortality, recruitment, etc, with error bars where appropriate. Residual plots are also drawn. These allow a visual assessment of the consistency of a model fit to be made simply and quickly. A post-processing projection programme allows calculation of stock projections, with associated estimates of error and risk.

A number of diagnostic plots are provided in order that the user may check that the data conform reasonably to the assumptions. Test statistics for goodness of fit, skewness and kurtosis are also provided.

The purpose of this Users' Manual is to provide a description for the installation, testing and data file configuration of the Integrated Catch-Age Analysis software. Although the manual is geared towards the practical aspects of getting the software up-and-running, an explanation of the various

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input parameters, output files, interpretation of results and common errors has also been included. Details of the analytical methodologies and programme source code are described in the Technical Reference and Programmer's Reference manuals.

To assist the user, the manual is divided into several sections which describe the hardware and software requirements, detail the installation and testing, describe data file formats, and includes step-by-step description of the input parameters for running the software.

## 2.0 Hardware Requirements

Both the analysis and the display programmes of ICA have been written and compiled for use on an IBM-PC compatible microcomputer, running MS DOS (Ver 5.0 or greater). The minimum configuration is a 80386 microprocessor with 640 K of conventional memory; however a 80486 microprocessor will greatly decrease the run time. A math co-processor, although not essential, will reduce computational time considerably. Currently the ICA package contains printer drivers for Hewlett-Packard LaserjetII and EPSON compatible printers. Only systems supporting one of these printer protocols can print from the display programmes.

The software contains two separate sets of PC executable routines, one for MS-DOS and the other for Windows. For smaller data sets it is recommended that the DOS version be utilized to improve the run speed. The Windows version is primarily for larger data sets and run speed penalties are incurred due to the system's memory manipulation. The North Sea herring data set, which is used as an example data set, does not require the Windows application. Windows users are cautioned that an error may occur when trying to run either of the DOS programmes from within Windows. This is due to an error in the Microsoft compiler; it is preferable to run only the Windows versions if Windows is running on the machine.

Regardless of the application, the programme is slow to run because of the extensive computational demands of the method. It is, however, possible to adapt the programme to faster machines such as a UNIX workstation. The programme is written in Microsoft FORTRAN and can be recompiled for most computers as long as an NAG workstation library is available. The graphics display programme is written in object-oriented Turbo PASCAL 6.0 and its application is restricted to IBM PCs for the foreseeable future.

## 3.0 ICA Software Presentation

The ICA software, Users' Manual and example data files are contained on a single 3.5 high density diskette. Examination of the ICA diskette will reveal the following three files and two sub-directories;

- ICA1_2.ZIP - File contains all the software programmes in a compressed form and is non-executable.
- PKUNZIP.EXE - This programme is used to unpack the ICA1_2.ZIP file into executable programmes during the installation process (Section 4.0). Note that this is a shareware product.
- ICAUSER.MAN - This file contains the Users' Manual in WordPerfect 5.1 format.
- Subdirectory: HERR_VPA - Contains a complete set of data files for testing and learning to use the software.
- SOURCE.ZIP - Contains the source code for the programmes in a compressed form. These files are not required to run the software. PKUNZIP will unpack the files if you wish to examine them.

## 4.0 Installation of Programmes and Test Data

### *4.1 DOS installation*

The following provides step by step instruction for installation of the ICA Programmes and the Test Data set. For ease of understanding we have chosen to **BOLDFACE** commands which are required inputs. This convention will be used throughout this manual.

a) Create a directory c:\ICA on your hard disk **(md c:\ica).**

b) Insert the ICA diskette in the disk drive (assumed = a: ).

c) From C:> Type **"a:pkunzip a:ica1_2.zip c:\ica"** followed by **"cd ica"** from DOS. This will uncompress all ICA files and put you in the subdirectory c:\ica.

d) If you do not wish to use the Windows versions then type **"del ????WIN.EXE"**. You may wish to retain this version for future use unless disc space is a problem.

e) You must now select the printer type output. If you have an Epson-type printer then type **rename *.eps *.exe**

If you have a printer with Hewlett-Packard LaserjetII compatibility then type **rename *.hp3 *.exe**

f) If you have neither printer, then use either one of the above, but you will not be able to print any graphs.

Upon completion of the above procedure your C:\ICA directory should contain the following files:

| | | |
|---|---|---|
| ICA1DOS EXE | 212412 01-04-95 | 1:20p |
| ICA1WIN EXE | 240888 01-04-95 | 1:18p |
| ICA2DOS EXE | 327816 01-04-95 | 1:29p |
| ICA2WIN EXE | 406674 11-16-94 | 2:04 |
| ICAVIEW EXE | 111168 10-26-93 | 12:56p |
| ICPROJ EXE | 342696 10-17-94 | 7:39p |
| VIEWPRO EXE | 83968 12-16-93 | 6:44p |
| VIEWSRR EXE | 81056 11-02-93 | 5:59p |
| VIEWPRO HP3 | 83968 12-16-93 | 6:44p |
| VIEWSRR HP3 | 81056 11-02-93 | 5:59p |
| ICAVIEW HP3 | 111168 10-26-93 | 12:56p |
| VIEWPRO EPS | 84032 12-23-93 | 2:39p |
| VIEWSRR EPS | 81056 12-23-93 | 2:40p |

g) To remove unneeded files type: **del c:\ica*.hp or del c:\ica*.eps**

The ICA software is now ready to run from your hard disk. If you wish to test the installation or familiarize yourself with the package using the test data set continue with the installation instructions.

h) To copy a test data set on North Sea herring, create a directory **md c:\herr_vpa** on your hard disk, and copy the data from the diskette : **copy a:\herr_vpa*.* c:\herr_vpa*.*** . Please note that you can put the test data in any directory or sub-directory you like (eg C:\ica\data), but you must ensure that when entering the filenames you type the complete address.

i) To copy a test projection file, **copy a:\fmult.dat c:\ica'.**

### *4.2 WINDOWS installation*

Proceed as above, then start Windows in the usual manner if you have not already done so. Then, from File Manager, make the choices : **File / New / Program Group / OK**; Then in the "Description" Box enter **ICA** and click on **OK**. Leave the Group File box empty. A new window will appear entitled ICA. Then make the choices **File / New / Program Item / OK**. A program item properties box will appear. Make the following entries:

| | |
|---|---|
| Description: | **ICA1WIN** |
| Command Line: | **C:\ICA\ICA1WIN.EXE** |
| Working Directory: | **C:\HERR_VPA** (or wherever you have the data you are working on) |
| Shortcut Key: | **None** |
| Run Minimised: | Leave blank |

and choose **OK**. Repeat the process for ICA2WIN, ICAVIEW and VIEWSRR. The ICA installation for Windows will then be complete and you will be able to run the programmes by clicking on the icons. You may wish to change the icons from the small icon library in the Program Manager. Each time you want to change the working directory to change to a new data set, select the icon, press Alt-Enter, and retype the working directory name.

## 5.0 Programme Limits

Memory size constraints currently limit the programme to accepting three indices of SSB and five age-structured indices, for 20 years of data, 13 age classes and 1,000 observations. No more than 75 parameters may be estimated (parameters are: selection

at age, fishing mortality at reference age, cohort strengths in the separable model; catchabilities at age; SSB catchabilities, recruitment in year after last year of catch at age data, a and b in the stock-recruit model). The complexity of the model that can be fitted also depends on the available memory at run-time. As this cannot be known in advance, the programme will check at run-time if sufficient memory is available. If there is insufficient memory available the user will be warned and the programme will stop. Releasing more conventional memory, such as by disconnecting from a network or disabling TSRs, may solve the problem. Otherwise it will be necessary to use the WINDOWS version. If the problem persists it may be necessary to install more memory in the machine.

File names and paths are limited to 40 characters.

## 6.0 Datafile Preparation

Careful preparation of data input files is critical to the successful operation of the ICA Software. Even a single mistyped or omitted character can cause the programme to crash. Many frustrating hours have been spent trying to locate a misplaced character or value. It is therefore recommended that users pay particular attention to data file formats.

The ICA datafile structure is a slightly restricted form of the well-known "Lowestoft VPA" format, which itself requires strict adherence to format. The following file description is a modified version of information presented in the Lowestoft VPA Manual. To further assist the user we have included a complete set of data files in Appendix 1 for the North Sea Herring (ie the test data).

To create a new data set the user will need to prepare the input data files using an external editor with ASCII output, such as MS-DOS EDIT or the Windows NOTEPAD. Three basic data file types are required for the ICA Software; a stock index file, stock data files, and one or more tuning files. Each of these will be discussed in detail in the upcoming sections.

### 6.1 *Stock index file*

The index or stock index file is the driving function of the software. Contained within this file is the stock title, sex option and a list of the data filenames which the ICA software will use to assess a given stock. To standardize labelling the filename extension ".ndx" (eg NSHERR.ndx) is recommended for this file. The following format is required for the stock index file:

| Record No* | Content | Index No |
|---|---|---|
| 1 | Stock title (80 characters maximum) | |
| 2 | Sex option (value 1 only) | |
| 3 | File name for "Landings (tonnes)" data | 1 |
| 4 | File name for "Catch-at-age (numbers)" data | 2 |
| 5 | File name for "Catch weight-at-age (kg)" data | 3 |
| 6 | File name for "Stock weight-at-age (kg)" data | 4 |
| 7 | File name for "Natural Mortality" data | 5 |
| 8 | File name for "Proportion mature-at-age" data | 6 |
| 9 | File name for "Proportion of F before spawning" data | 7 |
| 10 | File name for "Proportion of M before spawning" data | 8 |

*Record numbers and index numbers are not contained within the field. The file contains only a title, the figure 1 and a list of file names, content and index number in free format.

Notes:

a) Filename order is important. Misplaced or misordered file names can cause the programme to stop.

b) Data filenames must include the full address of a file, *drive\path\filename*. For example *"C:\ica\nsherr.ndx"*

c) No provision has been made for dealing with discard data separately. If this information is available it should be included by summing landed catch and discards.

d) File names and paths must not exceed 40 characters.

## 6.2 Stock datafiles

The stock data files are the files which contain information about the stock being assessed; such as catch, weight-at age, mortality estimates, etc. All stock data files have a common base format, but some differences occur in the layout of the actual data, where the structure is defined by the data format identifier (DFI) record. Three data structures are accepted by the ICA software:

| DFI code | Data structure | Example files |
|---|---|---|
| 1 | Two dimensional array | NSHERRSW.DAT |
| 3 | Scalar value | NSHERRPF.DAT |
| 5 | Column array | NSHERRLA.DAT |

The base format for each stock data file is:

| Content | | Record No |
|---|---|---|
| Title (80 characters maximum) | | |
| Sex (1 only) | Index No | 1 |
| First Year | Last Year | 2 |
| First Age | Last Age | 3 |
| DFI (1,2,3 or 5) | | 4 |
| (1st year) Data ... (by age) | | 5 |
| - | | 6 |
| - | | . |
| - | | . |
| - | | . |
| (last year) | | n |

For ease in identifying data files it is recommended that the convention suggested below be used to label data files; remembering that DOS filenames cannot exceed eight characters. The standard extension is ".dat". Data filenames should contain a 2-3 letter identifier for the stock, 2-4 letters for the species and two letters for the file content. Thus, for the test data filename NSHERRLA.DAT, NS refers to the North Sea, HERR to herring and LA for landings. Recommended file content characters are:

| Characters | Description | Example |
|---|---|---|
| LA | - landings (tonnes) | 14.2 |
| CN | - catch-at-age (thousands) | 14.3 |
| CW | - catch weight-at-age (kg) | 14.4 |
| SW | - stock weight-at-age (kg) | 14.5 |
| NM | - natural mortality | 14.6 |
| MO | - maturity-at-age ogive | 14.7 |
| PF | - proportion of F before spawning | 14.8 |
| PM | - proportion of M before spawning | 14.9 |

An example of each data file for the North Sea herring is provided in Appendix 1.

The ICA programmes calculate projected populations for one year ahead of the catch-at-age matrix. For example, if there are data on catches up to 1992, the programmes will calculate populations up to 1 January 1993; if there are observations of indices of abundance during 1993 then the programmes will also need to calculate the populations at the times of the survey indices. This can be done on the assumption that F in 1993= F in 1994, or else by specifying missing catch-at-age observations in 1993. However, it becomes necessary to have some estimates of maturity ogives, stock weights and natural mortality for this additional year. If desired, the MO, NM and SW files can be extended by an additional year in order to input these data, in which case the file headers must be modified accordingly. Otherwise, the programmes will use the data in the last year of the catch-at-age observations as estimates for the following year. A message to this effect is displayed to the user when this is done.

Data files which contain insufficient data will cause ICA to stop. For example, if the year range indicates 12 years of data and only 11 are included in the file the programme will terminate. However, the converse case of excess data will not cause the programme to stop as the additional data is ignored. It is thus important to ensure the file header matches the data.

## 6.3 Indices of abundance

The "tuning files" contain indices of stock abundance that are independent of the catch-

at-age data set. They are also referred to as abundance indices, and for ICA fall into two categories; age-structured and SSB index files (non-age structured), either or both of which can be used in any analysis. There may be up to three SSB indices and five age-structured indices. In the case of age structured tuning data the following format is required. Again data structure is critical to the successful operation of ICA (see Section 14.10). Up to five age-structured indices ("fleets" in demersal parlance) may be included.

### *6.3.1 Age-structured datafile format*

| Record No* | Description |
|---|---|
| 1 | File title (maximum 80 characters) |
| 2 | Number of fleets (+100) |
| 3 | Fleet name (maximum 20 characters) |
| 4 | First year Last year |
| 5 | Sex code Effort code Alpha Beta |
| 6 | First age Last age |
| 7 | (1st year) Effort value** Catch numbers (by age) ...→ |
| . | - |
| . | - |
| n | - (Last year) ↓ |

*Record numbers are not included in the file.
**Effort values will usually all be = 1 for survey data

Records 3 to 7+ are repeated for each age-structured index. Note a run-time error may occur if software limitations are exceeded (see Section 5.0). Use Windows Version when memory constraints are expected.

General description of records:

| | |
|---|---|
| File Title | - contains a description of fishery being assessed. |
| Number of indices | - 100 + number of indices in the file. |
| Index Name | - Name of Index (eg acoustic, Bottom Trawl, etc) |
| First Year | - first year of data in index |
| Last Year | - Last year of data in index |
| Sex Code | - Must be 1 to retain compatibility with old data |
| Effort Code | - Must be 1 to retain compatibility with old data |
| Alpha & Beta | - Start and end of the survey period for the index in decimal parts of a year |
| First Age | - First age in the index |
| Last Age | - Last age in the index |

### *6.3.2 SSB datafile format*

Age-aggregated indices of spawning stock biomass (SSB), such as larval surveys are also accepted by the ICA software. Details of how the programme incorporates these data are provided in Section B (Technical reference). The file structure is however different from the age-structured tuning file in that it follows the Lowestoft RCT3 format (see example file NSHERR.RCT, Section 14.11), the structure of which is described below. The first data column holds the year of the observation, the second column is a stock size estimate from a historical VPA and each of the other columns an SSB index. A maximum of three indices is permitted. The second column is ignored by ICA.

| SSB data file format | Record |
|---|---|
| 1 | Data file title |
| 2 | <Number of Indices> <Number of Years> 2 |
| 3 | Index or indices labels (maximum of 8 characters each) |
| 4 | Year VPA Data SSB Index 1 SSB Index 2 ...→ |
| . | - |
| . | - |
| n | - (by year) ↓ |

*Record number is not contained within the file.

The records in the SSB datafile are:

| | |
|---|---|
| Record 1 | - Title of data file (less than 40 characters) |
| Record 2 | - Number of indices<br>- Number of years<br>- 2 , for RCT3 this holds the column number for VPA |
| Record 3 | - Contains the indices labels, one maximum eight character name for each. Again this is for RCT3 compatibility. ICA does not use them. |

Notes:

a) Because this file uses the RCT3 format a number of input parameters are not utilized by the ICA Software. Record 2 contains the number of indices, the number of years and the column position for VPA data of the RCT3 programme. Since ICA ignores the VPA data any number in column 2 of Record 4 or greater is not used. It is important however that some value be put in column 2, otherwise the ICA model will confuse it with survey data. Record 3 although required in the file is also ignored by ICA.

b) Year must be written out, eg 1995.

c) Any negative value is considered a missing value.

## 6.4 Stock-recruitment datafile format

The ICA programmes can be used to fit a stock-recruit relationship with up to the 20 years of allowed catch at age data. However, when attempting to fit such a relationship it is highly desirable to include data from as long a time-series as possible. The programmes allow the inclusion of up to a further 20-*lag* "observations" of stock and recruit if these are available from external estimates such as a historical VPA. The *lag* is the number of years between spawning and the first age in the catch-at-age matrix. If users wish to include such estimates in the fitted relationship they must prepare a data file with the following format (Example Section 14.2):

| Record No* | Description |
|---|---|
| 1 | Year in which data begin |
| 2 | (1st year) <Stock Size> <Number Recruits> |
| . | - |
| . | - |
| n | (Last year) ↓ |

*Record number is not contained within the file.

Note: the data contained in this file are only for years which are not covered by the ICA input data. The programmes will seek to read stock and recruit "observations" from the year stated in the first line, up to the first year at which there are catch-at-age observations in the main data set.

## 6.5 Zeroes and missing values

Catch at age matrices can be highly variable at the youngest and the oldest ages, with gaps in some years when no fish of certain ages were found in the samples. This causes difficulties as in neither the conventional VPA nor in the separable VPA is it allowable to have a zero observation. In the former case, a zero catch implies a zero F in which case the VPA will not work, and in the latter case it is assumed that catches at age have a log-normal error distribution, which implies that the observation will never be zero.

The usual way of dealing with this problem in conventional VPA is to replace the gap in the table with a low value, which might be an arbitrary figure or might be the lowest of the remaining non-zero observations. If the ICA programmes encounter a zero (defined as values between 0.0 and 0.1) then the following procedure is used:

a) If the zero value is not the terminal value, the lowest observed value in the catches-at-age is inserted in the data matrix and the conventional VPA calculation will be made, so estimating a very small fishing mortality.

b) If there is a zero value at the last age, the programme will trace back up the cohort until a non-missing catch at age

observation is found. A terminal population will be estimated using the terminal fishing mortality estimated for the oldest age in the year of the observation, corrected for the estimated selection at the actual age. The cohort will then be filled-in forwards using the estimated terminal mortalities for the relevant years, as corrected for the estimated selection at the relevant ages. This allows the fitting of index values even where the catch-at-age observation is zero.

**It is the users' responsibility to make sure that input data are scaled so that few of the observations lie between 0 and 0.1, otherwise much of the data will be overwritten.**

An alternative way of dealing with such gaps is available, provided that the gap lies in the range of years and ages over which the separable model is to be fitted. The gap can be treated as a "missing value" in the statistical sense when the model is fitted. In such cases,

- The observation is ignored when the separable model is fitted.
- No residual is calculated for the observation, but an arbitrary value of -1 is printed in the residuals table in the output file.
- Output from the ICA1 programme should be ignored

In order to specify a value as missing, a negative number should be entered in the catch at age data file. The value of this number should be the best available estimate of the catch at age, as the quantity will be used when calculating the starting point for finding the solution. It is possible to specify an entire years' data as missing, but in such cases the variance of the estimated fishing mortality will (not unreasonably) be extremely large.

In summary: if a value in the catch at age matrix is between 0 and 0.1 it will be reset to the lowest non-zero observation. If it is given as a negative value it will be used for initialisation but thereafter treated as a missing value. The latter option may only be used for the range of years over which the separable model is fitted.

### *6.6 Units and scaling*

It is recommended that the user enter catch numbers in thousands and weights in the catch and stock in Kg. If other options are chosen the output table headings will be incorrect. All mortality rates are assumed to be annual rates.

## 7.0 Running ICA

This section describes an illustrative ICA run using the example data set. Following this example should enable the new user to duplicate the output tables and graphs presented in Appendix 2.

Once all the data files have been prepared and checked for accuracy you are ready to undertake an assessment calculation. The ICA software is comprised of two main executable routines; **ICA1DOS.exe** and **ICA2DOS.exe** (Windows equivalents are ICA1WIN and ICA2WIN), and two graphical display programmes; **ICAVIEW.exe** and **VIEWSRR.exe**. Appropriate parameter selection is made within the former two programmes. The specific input parameters will be discussed after a general statement of what each programme does.

The **ICA1DOS.exe** programme is the initialisation routine which performs the functions preparatory to the least-squares analysis. Datafiles are read, appropriate parameter choices are requested from the user on the screen, and an initial estimate of the minimum is found. Over a range of terminal fishing mortalities specified by the user, the sum of squared residuals for each index series are calculated. The programme then produces an output file called ICA.TMP. This is a temporary data file used to pass values on to another programme, in this case to the ICA2DOS programme. A summary of the ICA1DOS routine is provided in Part 2 of Section B (Programmer's Reference Manual).

The **ICA2DOS.exe** programme performs the

multidimensional minimisation, reweighting and output functions. This programme initially accepts a choice from the user about whether reweighting is to be used. The user must also specify a stopping criterion for the reweighting iterations. A note of caution is appropriate at this point. Users may find that due to memory limitations this routine stops with an insufficient memory error. If this occurs you can run the Windows version of ICA2 from Windows. The problem is also often encountered when running the DOS version with Windows still active. Alternatively, you can re-boot your PC for DOS only.

The **ICAVIEW.exe** programme displays a number of summary and diagnostic graphs on the screen, which can be written to a printer if necessary. Simply type ICAVIEW from DOS and the programme will read the files "ICADIAG.OUT", "ICA.VIE" and "ICA.RES" and display the appropriate graphs.

The **VIEWSRR.exe** is another simple utility which reads a file called "ica.srr" which is generated by ICA1 or ICA2 when a stock-recruit relation is fitted. Graphs of recruitment on SSB; residual on expected recruitment, and residual on time are displayed.

## *7.1 The ICA1 routine: initialisation*

The following provides step-by-step instructions for running the ICA1 routine. For each step a brief description of what is required is provided. If an input parameter has several options or a limited range these are also explained. For the sake of consistency we have chosen to highlight executable programmes in **BOLDFACE CAPITAL** letters. The example data set input filenames and their associated addresses will be used for illustration. These will appear in **small letter boldfaced** print.

### *7.1.1 Specifying input datafiles*

The ICA programme is started by typing ICA1DOS from the C:\ica> prompt.

C:\ica>**ICA1DOS**

or from Windows by double-clicking on the icon.

You will then be prompted on screen for a series of input files. The first file requested is the stock index file (See Section 6.1); Note you must specify the complete address of the file.

Enter the name of the index file —> **C:\herr_vpa\nsherr.ndx**

This is followed by an on-screen listing of the data file names contained within the index file.

The next request is for the age-structured index filename (Section 6.3.1). If you do not have this type of tuning data or if you do not wish to include it in the analysis press ENTER.

Name of age-structured index file (Enter if none) —> **C:\herr_vpa\nsherrfl.dat**

The final request for file input is for the SSB index file (Section 6.3.2). Again if you do not have this type of data available or you do not wish to include it in the analysis press ENTER. You must however input either an age-structured or SSB index file or the programme will not run.

Name of the SSB index File (Enter if none) —> **C:\herr_vpa\nsherr.rct**

Once all the data files have been read by the programme you will be prompted to make a series of selections. To aid you in responding a brief description of the input variable and their range limitations have been included.

### *7.1.2 Resetting the last year*

The last year of the catch-at-age from the input data is displayed, together with an option to change it.

Last year of catch data set is 1994

Press <Enter> to Accept or else a new last year —>**1994**

This option is presented in order to allow retrospective testing without changing the input data files. If the last year is reset by (say) two years, all the data series will be

shortened by two years. This allows the timing of the last years of the indices with respect to the last year of the catch-at-age data to be maintained consistently in the retrospectives, as is required when using a recruitment index in the model.

### *7.1.3 Parameters of the separable constraint*

You will now be prompted for three parameters to constrain the exploitation pattern. These work in exactly the same way as in the Lowestoft VPA, and are:

a) The number of years for the separable constraint. The Lowestoft programme suggests six years as a suitable choice for this parameter. Choosing less than three years will cause an error as there will be insufficient data to estimate the exploitation pattern from so few data. Choosing a large number of years is likely to use up too much memory in the minimisation. Sensible choices for this parameter would seem to lie in the range 3 to 10 years.

No years for separable constraint ? —> **3**

b) The reference age for separable constraint. This should be your estimate of the first fully-recruited age group. Error-trapping in the programme will reject values that are within one year of the first age or within two years of the last age. Age 4 is normally used for herring.

Reference age for separable constraint? —> **4**

c) The selection to be fixed on the last age group. As for conventional separable VPA, this should be a number of the order of 1.0, depending on prior prejudice about the exploitation pattern. Error-trapping in the programme limits this choice to the range 0.4 to 1.7.

S to be fixed on last age ? —> **1.0**

d) The first and last age for calculation of the reference F is requested next. The "reference F" is simply an arithmetic mean F over a defined age-range that is used for administrative purposes. It is calculated within the programmes for convenience but the choices made here do not affect the model fit. Any convenient age-range can be selected as desired, eg

First age for calculation of reference F —> **3**

Last age for calculation of Reference F —> **6**

### *7.1.4 Specification of weights on the catches at age*

Default weighting can be chosen, in which case all ages will be weighted equally (ie = 1.0) for the separable constraint;

Default weighting (Y/N) ? —> **N**

Otherwise, you will be prompted for a relative weight at each age, relative weights by year and specific weights for year and age which can be entered by hand:

Enter relative weights at age:

Weight for age 0 —> **0.01**
Weight for age 1 —> **0.5**

.

.

Weight for age 9 —> **1.0**

Enter relative weights by year
Weight for year 1992 —> **1.0**
Weight for year 1993 —> **1.0**
Weight for year 1994 —> **1.0**

A weighting matrix by year and age will be formed as the product of the weights on the years and the ages. It may occasionally be desirable to downweight one or more outlying observations, or perhaps to downweight an entire cohort which may be atypical. The next option allows you to overwrite any of the values in the weighting matrix.

Specify weights for year and age:
Enter year, age, new weight
or -1, -1, -1 to finish
**-1, -1, -1**

In most cases it will be unnecessary to make use of this facility and typing -1 three times will allow you to proceed to the next section.

Relative weights at age are the ratio of the inverse log variances of the catch-at-age observations compared to the survey indices and to each other. You would normally choose to set all equal to one, except at those ages which are highly variable in the catches, such as perhaps the first and oldest ages. Ideally you should calculate these variances from the catch sampling procedure.

### *7.1.5 Plus-group specification*

After entering the constraints for exploitation pattern the programme will request additional information on the catch at age indices. The last age of the catch at age data is assumed to be a plus-group. Since this is not the case for the age structured indices, the user must specify at run-time which of the indices has a plus-group as its last age. Note that the choice is most important in the case of a recruitment index: a mistake here will lead to the entire stock size being tuned by the recruitment index! It is recommended that the user record the order in which the indices are contained in the data file to avoid such an error. The request for input refers to the order in which the indices are read.

> Is the last age of index 1 a plus group ? (Y/N) —> **Y**
>
> Is the last age of index 2 a plus group ? (Y/N) —> **N**
>
> Is the last age of index 3 a plus group ? (Y/N) —> **Y**
>
> Is the last age of index 4 a plus group ? (Y/N) —> **N**

### *7.1.6 Choice of model*

For each index you will be prompted for a choice of catchability relationship. Allowable options are A, L, or P for Absolute, Linear or Power. The term "catchability" is used to indicate a quantity referring to the relationship between the stock size and the abundance index in order to maintain the same terminology for both the pelagic and demersal cases. The catchability models in ICA include (1) a direct identity relationship, in the case of some acoustic survey estimates that have been treated as estimates of absolute stock size; (2) power relationships, as in the case of larval surveys where it is thought that larval production may well be a power function of spawning biomass, and also in the case of demersal trawl surveys where it is thought that catch rates may be a power function of stock size on account of concentration effects; (3) Linear relationships have also been used where acoustic survey indices have been treated as proportionate indices of abundance. Note that the "absolute" option should only be used if the index of stock size is expressed in metric tonnes (assuming that the catch numbers are entered in thousands and the weights-at-age are in kilograms. Formally these relationships are:

(1) $\text{Index} = \text{Stock Size}.e$

(2) $\text{Index} = Q.\text{Stock Size}^{K}.e$

(3) $\text{Index} = Q.\text{Stock Size}.e$

where Q and K are parameters to be estimated, and e is a lognormally distributed error term.

Model choices are made in the programme by simply responding to the questions:

> Model for SSB index 1 is to be (A/L/P) ? —> **L**
>
> Model for aged index 1 is to be (A/L/P) ? —> **L**
>
> Model for aged index 2 is to be (A/L/P) ? —> **L**
>
> Model for aged index 3 is to be (A/L/P) ? —> **L**
>
> Model for aged index 4 is to be (A/L/P) ? —> **L**

### *7.1.7 Fitting a stock-recruit model*

If you respond yes to the request for a stock-recruit relationship;

> Do you want to fit a stock-recruit relationship ? —> **Y**

the programme will request a lag time in years and a data filename (specify the complete path), if any, for the estimates of stock and recruitment prior to the first year of

age-structured data. The specification of this time lag will depend on criteria used to age the fish. In other words, it is necessary to specify the real age of the "recruits" so that they can be matched to the appropriate spawning. The format for this datafile is described in Section 6.4. It is necessary to fit a generate a stock-recruit relationship if projections are to be run with the ICPROJ programme.

Enter the time lag in entire years between spawning and the stock size of fish aged 0 on 1 January —> **1**

If there are any estimates of stock and recruitment prior to the first year of age-structured data, enter the name of the file where they are held, or else press return —> **c:\herr_vpa\srr.dat**

If you respond "no" to the offer of a stock-recruit relationship, these prompts will not appear.

### *7.1.8 Initial analysis*

On completing the basic input procedures a summary table of the input data is shown. You must next specify a range of feasible fishing mortalities for the stock. It is prudent to choose a rather wide range for these: for herring in 1992, a range of 0.05 to 1.0 seems appropriate. The range of F is restricted between 0.04 and 3.0. Values outside the range will cause an error and a request for re-entry of the F values.

| | | |
|---|---|---|
| No of years for separable analysis: | 6 | |
| Age range in the analysis: | 0 | 9 |
| Year range in analysis: | 1974 | 1992 |
| Number of indices of SSB: | 1 | |
| Number of age-structured indices: | 4 | |
| Stock-Recruit relationship to be fitted | | |
| Parameters to estimate: | 34 | |

Enter lowest feasible F —> **0.05**

Enter highest feasible F —> **1.0**

The machine will now complete the initial analysis using the input values provided.

The implemented fitting procedure works in three stages. The first of these is a simple procedure designed to indicate whether the indices (with their specified catchability models) are consistent in their estimates of stock size. Initially 20 separable VPAs are run with equal intervals of F over the specified feasible range. For each separable VPA, a "best fit" of the tuning indices using the appropriate catchability model is calculated. The results of these analyses are written to a file named ICADIAG.OUT, the contents of which are displayed as the first graph in ICAVIEW. Interpretation of this graph is described in Section 8.1.

The programme then undertakes a simple searching procedure to find an approximate minimum, from which the formal minimisation procedure can begin. If a stock-recruit model fit has been requested, parameters are calculated by a linear regression approximation. If no reasonable estimates can be obtained, the programme will terminate with an error message. Details of these calculations are given in the Technical Reference Manual. The ICA1 programme finishes here.

## *7.2 ICA1 output*

Once ICA1 has been run successfully the user will find several new files in the ICA directory which contain a summary results file and a number of intermediate files for internal use. The output filenames are displayed in boldface followed by a brief description of their contents for reference below.

a) **ICA.OUT** is the principal results output file. It contains in flat ASCII format the input data set including the tuning indices used, the matrices of F and of population numbers, and the spawning stock biomass estimated from the least-squares fits to the data. Lastly, each of the fitted parameter estimates is listed together with its estimated upper and lower standard deviation bounds. Residuals of the fitted catches and fitted indices are given, as well as tables of summary statistics for each index (Section 15.1).

b) **ICA.VIE** holds some of the quantities to be displayed by ICAVIEW, including observed data and their predicted values from the calculated parameter estimates. Data in this file are used for the residual plots. The file may also be useful for reading into a spreadsheet and plotting additional graphs. Recruitment, stock biomass, SSB and landings are summarised here (Example Section 15.2).

c) **ICA.RES** holds a list of the observed and fitted values calculated for the model fit. This file also is read by ICAVIEW and its contents displayed graphically.

d) **ICA.AV** holds the analysis of variance table.

e) **ICADIAG.OUT** holds the estimates of the error about the tuning indices when fitting them to a range of separable VPAs fitted with reference fishing mortalities ranging from 0.1 to 2.0.

f) **ICA.TMP** is a temporary file used to pass values from ICA1 to ICA2 and from ICA2 to ICPROJ.

g) **ICA.SRR** holds estimates of stock size and observed and expected recruitment by year. It is generated by either ICA1 or ICA2 when a stock-recruit relation is fitted.

h) **ICA.VC** holds the variance-covariance matrix and the parameter correlation matrix.

You may run the ICAVIEW programme to obtain a "quick and dirty" look at the fit (Type ICAVIEW from DOS), but most importantly an approximate view of the reference fishing mortality dimension of the least-squares surface over which the minimisation is to be run can be seen before entering the full minimisation routine. Checks that the model fit appears consistent and that there and no multiple minima exist on the F-surface should be made at this stage. No estimates of the standard deviations of the parameter estimates are available here.

## *7.3 The ICA2 routine: minimisation and reweighting*

The ICA2 programme can be run from DOS by typing:

C:\ICA> **ICA2DOS**

or from WINDOWS by either double-clicking on the icon or from File Manager.

Note: If insufficient memory is available in DOS to estimate all the required parameters, the programme will terminate with a warning message. Therefore, it is preferable to free as much DOS memory as possible (eg removing network connections), but if this does not solve the problem, then the windows version of ICA2 can be run. This entails a speed disadvantage as the programme will take around 1.8 times longer to run.

The ICA2 programme works using a modified Gauss-Newton algorithm implemented in the NAG FORTRAN library (Routine E04FDF). Subsequently an auxiliary routine is called which calculates estimates of the variance-covariance matrix for the estimated parameters. These can be used to estimate parameter correlations, and to provide estimates of the standard deviations of the parameter estimates. These are printed to the output files and may be viewed as text in the ICA.OUT file or using the ICAVIEW programme.

The programme will present two options for assigning weights to the abundance indices relative to the catch-at-age data. These are:

1 - Recalculate all weights iteratively

2 - Enter new weights by hand

a) Full reweighting: all the index weights are recalculated according to an inverse-variance regimen. If there are few, noisy data this procedure will be unstable and may lead to wholly erroneous results.

b) Manual reweighting allows new weights to be entered by hand. This should be used in cases where independent

estimates of the relative variances of the indices and the catch-at-age data are available or are to be fixed at determined values. If these values are unknown it may be appropriate to specify equal weights for all the surveys. Choose this option to proceed with the example.

Enter your choice —-> **2**

c) The programme will request a weight for each biomass index and a weight for each aged index. To continue with the example, enter "1" for all the weights:

Enter weight for biomass index 1 —> **1.0**

Enter weight for aged index 1 at age 2 —> **1.0**

Enter weight for aged index 1 at age 3 —> **1.0**

" " " " " " "

-

-

These weights should ideally be the best available estimate of the ratio of the variance of the logarithms of the catch-at-age observations to the variance of the logarithms of the survey observations at each age.

A further quantity needs to be specified by the user for each age-structured index series: this figure represents the extent to which it is expected that errors in an age-structured index are correlated across ages. Consider the example of an age-structured index of stock size which is obtained by first estimating a measure of total stock size $I_{tot}$, which is then apportioned across a number of age-groups to yield an age structured index $I_{age}$. If the principal source of error in the index lies in the measurement of total stock size $I_{tot}$, then the errors in the $I_{age}$ values calculated will be highly correlated. If however the main source of error lies in the repartition of $I_{tot}$ amongst ages, then the errors will be much less strongly correlated. The weighting structure of the model needs to be slightly different according to which of these conditions is most likely to pertain, and the programme will request from the user a value from 0 to 1 which should reflect the user's perception of the interdependence of the errors in each age-structured index.

The screen output and request for input varies depending on the option selected. For Option 1 the following request for information will be displayed on the screen:

You should enter estimates of the extent to which errors in each age of the age structured indices are correlated. These may range from zero (independence) to 1 (correlated errors).

Enter value for aged index 1 —> **1**

Enter value for aged index 2 —> **1**

Enter value for aged index 3 —> **1**

Enter value for aged index 4 —> **1**

Do you want to shrink the final populations ? (Y/N) —> **N**

If the shrinkage option is chosen the model will calculate a conventional VPA in which the terminal fishing mortalities are calculated from an inverse-variance weighted mean between (1) the average historical F over a time-period that is specified from the screen, and (2) the terminal F estimated from the model fit. The calculations are carried out separately for each age, and the variance of the F from the model fit is calculated from a linear approximation from the variance of F at reference age in the terminal year, and the variance of the estimate of selection at each age. The matter is described in detail on page 7 of the Technical Reference. Note that choosing the shrinkage option does not affect the model fit written to ICA.OUT and ICA.VIE; the shrunk VPA is written to a file named ICA.SHR.

If the iterative reweighting option is chosen, then after an initial analysis run using all weights assumed = 1, further analyses calculated using weights derived from the variances about the previous model fit are calculated. This process is iterated until the

fishing mortality at the reference age changes by less than a specified amount. This quantity must be specified after the reweighting menu. A suggested suitable value is 0.005, which means that the iterative reweighting will stop if the fishing mortality at the reference age changes by less than 0.5% between iterations.

The analysis will be repeated with recalculated weights until reference F changes by a proportion less than a specified tolerance.

> Enter your choice for this tolerance —>
> **0.005**

Execution time varies considerably with the size of the data set, the complexity of the model and the PC's speed. The results given in Appendix 2 (Sections 15.1 and 15.2) were obtained after some 10 mins. processing time using a 33 MHz 80486DX processor. The model will often find a stable solution in about three iterations. A summary of index weights, SSQ, and F is written to the screen after each iteration.

A note of caution: There is a cost attached to the use of the reweighting procedure. The method estimates a set of variances at age for each survey, thus increasing substantially the number of parameters estimated by the programme. It is not possible to estimate these variances well if there are few data, and attempting to do so may lead to unstable results.

Once the input requirements have been entered the programme will complete its computational procedures. If these have been completed successfully a diagnostic value of "E04FDF IFAIL = 0" or "E04FDF IFAIL =5" will be displayed. If the minimisation procedure fails to converge satisfactorily, a message to this effect will be displayed on the screen. Note however that all the usual output files will still be generated; it is the users' responsibility to check that the minimisation has worked successfully and that the resulting solution is acceptable.

## 8.0 Interpretation of Results

The input data set and the estimated population sizes are held in a file named "ICA.OUT", which is the principal output file for the system (Section 15.1). This holds:

- The catches at age
- The survey data
- The estimated population sizes
- The estimated fishing mortalities
- Summaries of recruitment, stock size and fishing mortality by year
- The parameter estimates and standard deviations
- Tables of residuals
- Statistical diagnostics

At the foot of the ICA.OUT file a small table of statistics is printed for the separable model fitting and for each index. The skewness and kurtosis test statistics are approximately normally distributed with zero mean and unit variance. Large positive or negative values of the skewness statistic indicate that the distribution of residuals is skewed to the right or left respectively; large positive values of the kurtosis statistic indicate that the tails of the distribution are broader than would be expected. In summary, values of either statistic further than (say) 2 from zero indicate that the assumption of lognormally distributed errors may not be justified.

Estimates of the variance-covariance matrix and of the parameter correlation matrix are held in a file named "ICA.VC". The "parameter numbers" correspond to those listed in the end of the main output file, "ICA.OUT". If any of the correlations in this matrix approach 1 or -1, this indicates that the estimates of certain parameters are strongly correlated. This can happen when both a separable constraint and an age-structured index are included in the model, as here effectively two sources of information are being used to estimate closely related parameters: catchability at age, and selection

at age: a low catchability implies a low selection.

The analysis of variance table is held in a file named "ICA.AV". This shows the sums of squared residuals that correspond to the separable constraint and to each index series. This table, which is also printed to the screen during the iterations, affords a quick and simple view of the main sources of variation in the model fit. Tables of unweighted and of weighted residuals by age are reported in this file.

### *8.1 Graphical diagnostics*

Type **ICAVIEW** from MSDOS. The programme requires no input from the user but will show a succession of graphs on the screen. Press "P" to print any one of these, or any other key to continue to the next graph. A sample of graphical output is given in Section 16. Note that if you do not have a compatible printer (Hewlett-Packard Laser-Jet II or Epson-compatible), the print function will not work properly. The graphs shown are:

a) An overall tuning diagnostic graph. This is a plot of the index SSQ against the F at reference age from a separable VPA. Ideally all the indices used should show U-shaped plots with minima fairly close to each other. If the minima are widely separated, this indicates that the model and the indices are inconsistent. A least-square solution, and especially an inverse-variance reweighted solution may not be meaningful in such cases. It may be worthwhile trying alternative catchability models in such cases.

b) A stock summary. Yield, fishing mortality, recruitment and spawning stock biomass are graphed together on a single screen. Over the period for which a separable constraint was fitted (eg six years) the programme will plot reference F from the separable model ± standard deviations; on previous years the plot is of F from the conventional VPA (initiated with the fitted model) at the reference age. Similarly, recruitment estimates for the years of the separable VPA will be plotted ± one standard deviation; prior recruitment plotted are recruitment estimated from conventional VPA initiated with the fitted model. If parameter estimates generated by ICA1 are being viewed no standard deviations will be plotted. The quantities graphed are described in detail in Section B (Technical Reference) but are summarised as:

   i) Yield. The yield plotted is simply the information held in the "landings" input file. The data held in that file are not used for any other purpose.

   ii) Fishing mortality. For the years over which a separable model has been fitted, the mortality graphed is the fishing mortality at reference age, ± the standard deviation of this parameter estimate derived from the estimated variance-covariance matrix. For earlier years, the quantity graphed is an estimate of the reference fishing mortality based on the assumption that the selection pattern in the earlier years was the same as that estimated in the separable analysis.

   iii) Recruitment.

   iv) The total stock biomass at 1 January and the spawning biomass at spawning time.

c) A summary of separable model diagnostics. This shows firstly a contour plot of the residuals about the separable model. This may help identify years or ages of atypical selection, as bright or dark patches. Strong diagonal banding patterns indicate changes in selection (fishing effort is concentrated or diminished on certain cohorts). Next the selection curve is plotted together with the ± standard deviation error bars. Note that no error bars are plotted for the reference age (assumed = 1); the last

true age (set at the terminal selection that was specified earlier); nor for the plus-group (set equal to S on the last true age). The two lower graphs show the marginal totals for the separable analysis residuals: if the model fits well to a separable constraint, these values will be close to zero. Deviations from zero indicate that the tuning indices are forcing the model fit away from a separable pattern, with respect to either ages or years.

d) For each index series, four diagnostic plots are drawn. The first of these illustrates the consistency of the index series with the fitted populations. The stock size estimate from the fitted populations is plotted as a continuous line, and the stock size prediction calculated from each index datum, using the appropriate catchability model and estimated parameters. The error bars indicate the range of the index prediction from (ln(index)+standard deviation) to (ln(index)–standard deviation).

The second plot is a scattergram of biomass estimated from the model fit against the index datum, together with a line indicating the relationship between the two that has been fitted in the model. The two lower graphs are conventional plots of residuals against expected value and of residual against time. Both these plots should show an even, random scatter of points with no discernable pattern. Any marked trends in the plots indicate that the starting assumption that errors are random and not correlated with time have not been satisfied. Curvature in the residual-expected value plot suggests that the catchability model for the index may be wrong; similarly a fan-shaped pattern of points indicates that the index error model (which here is assumed to be a lognormal distribution) may be inappropriate. Any trend in the residual-time plot indicates that the relationship between the index and the stock size is not consistent between years; among other effects this could be due to an erroneous catchability model in a situation where there is a trend in stock size, or to a failure to maintain consistent sampling between years.

These four graphs are plotted for each biomass index and for each age of each age-structured index. A full description of the quantities plotted is given in the Technical Reference Section.

### *8.2 Caveats*

Appropriate use of these programmes depends on a careful attention to a suitable model specification. If wholly inappropriate models are specified for the dataset in use the resultant model fits may be grossly misleading. It is necessary to examine critically the diagnostics and distributions of residuals to ensure that the model fit is consistent with the starting assumptions (see Section 1.3). It is an inescapable feature of a programme of this type which is intended to allow the experienced user to explore a wide range of model structures that the possibility that an inexperienced user may generate a wholly inappropriate model fit is correspondingly greater than is the case for a more restricted programme. In many cases it will be helpful to examine the sensitivity of the stock assessments to different model formulations.

The following is quoted from Fournier and Archibald (1982):

> "It is simply an inescapable fact that the age structure and effort data do not contain enough information to determine the relative accuracy of the aging data, the total catch data, the regularity of fishing mortality or the closeness of the relationship between effort and average fishing mortality. These procedures do however give the user a precise quantitative method of exploring the results of various assumptions about the relative error sizes involved."

## 9.0 Stock Projections with Variance Estimates

### *9.1 Background*

The Methods Working Group (Anon., 1993a) indicated a need for a method which would allow medium-term calculations of likely stock

trajectories, including a consideration of uncertainty and risk. Projections of this type have heretofore been calculated using simulation methods (Anon., 1993b). An alternative approach is to make the simplifying assumption that the stock projection is a deterministic process which is conditioned upon a number of fixed parameters (Specified F-multipliers, weights at age by fleet, natural mortalities, etc) and a set of parameters which are estimated with observation error and for which a variance-covariance matrix is available (Selection at age, numbers at age, fishing mortality, stock-recruit parameters). Such an approach may have advantages of simple and rapid calculation of different F - multiplier options once a stock assessment model has been fitted. A programme to allow the testing and evaluation of this method has been included as a post-processing option. Use of this option presupposes that the Beverton and Holt stock-recruitment function fitted in the ICA method is realistic approximation to the observed history of stock and recruits. At least for North Sea herring, this appears to hold true, although there is obviously strong interannual variability about the stock-recruit relationship.

The programme documented below has only recently been implemented. It is provided for testing and evaluation purposes only.

## 9.2 Implementation

The ICPROJ programme has been provided here as one of a number of possible approaches to the problem. Here stock sizes in succeeding years are calculated in a deterministic way from the terminal populations of the stock assessment, and the specified fishing mortality multipliers and fleet catch ratios at age. Estimates of the variance-covariance matrix are then used to assess the uncertainty about the deterministic path by the delta-method (Section 6.3). The programme is simple to run:

a) Type "ICPROJ" from DOS.

   **C:\ica\icproj**

b) The programme will then prompt for the name of the projection file (in this the example file is FMULT.DAT). The format of this file is discussed in the next section.

   Enter the name of the projection file —>**C:\ica\fmult.dat**.

c) Natural mortalities, maturity ogives and weights at age in the stock to be used in the projections are calculated by taking over a mean of the ultimate years of the original data set. The user must specify the number of years over which these means are to be taken.

   Population parameters for projections are set by taking the mean over a number of the last years of the data set.

   Specify the years for taking these means.

   Use mean natural mortality from 1992 back to —>**1990**

   Use mean maturity ogive from 1992 back to —>**1990**

   Use mean weight at age in the stock from 1992 back to —>**1990**

d) The user must also specify the MBAL in metric tonnes.

   Enter the minimum acceptable spawning stock size —>**800000**

## 9.3 Projection file format

An example of the projection file format is given in Appendix 1 (Section 14.13) as FMULT.DAT. Much of this data file is self explanatory. However, since the projection is based on terminal F estimated with uncertainty, it is not feasible to treat fleet partial F as an input parameter. Thus, the ratios of the catches in number by fleet to the total catches must be specified. In other words the ratios sum to 1 across each age group. These are then used internally to calculate partial Fs in the usual way.

The F Multiplier by year is the ratio of the fishing mortality exerted by each fleet in each year to the last year in which catch at age

data are available. For example, if a fleet exerts a partial fishing mortality of 0.4 in the last year of catch data and if all the "F-multipliers" are set to equal 1 in subsequent years, it is assumed for projections that this fleet will continue to exert a fishing mortality of 0.4 in future years. If for any year the "F-multiplier" is set to 2, then this implies that the fishing mortality for that fleet will rise twofold to 0.8 in that year. In the example projection scenario given, the effect of reducing the fishing mortality exerted by the second fleet (Fleet B) by 25% is calculated.

### *9.4 Projection output*

Three files are created by the programme. Estimates of the populations in the projections are written to "PROJECT.POP"; The projected stock sizes and catches, together with their variance estimates and estimates of the probability of stock size falling below MBAL, are written to "ICA.PRO". The first part of the ICA.PRO output file holds four columns: (1) Year; (2) Spawning stock size at spawning time; (3) Variance of the spawning stock size; (4) Probability that the spawning stock size will be below MBAL. In the following section the projected catches and their estimated variances by fleet are given.

Lastly for diagnostic purposes, the vectors of derivatives of dX/dC and dX/dS for each year of the projections are written to a file named "DERIVS.TST" (where X: parameter estimates; C: catch by fleet; S: Spawning stock size). Estimates of risk are calculated on the assumption of normal distribution of the estimated stock size and catches. This assumption is more conservative than the assumption of lognormality made in Anon. (1993b).

Graphical results can be obtained by running "VIEWPRO" from DOS. This programme reads the ICA.PRO file and draws appropriate graphs. Example output from VIEWPRO is given in Section 17.

## 10.0 Common Errors

a) Run-Time error (File not found). The most common source for this type of error is the incorrect spelling of a filename or its full directory address.

Solution: Using a standard editor, edit the index file so that it contains the correct locations (ie sub-directory) of the example data files.

b) Insufficient memory available to programme. This error generally occurs when running ICA2DOS with larger data sets from DOS. It is also more likely to occur if the other software (such as Windows or netware) is running in the background.

Solution: Remembering there is a time compromise between the DOS and Windows version of ICA, the user can either; (a) reboot the system for DOS only, thereby making more memory available, or (b) use the Windows version of ICA.

c) Another common runtime error occurs when one or more of the data file formats are incorrect or incomplete. For example, early versions of the test age-structured tuning data file did not contain a "Alpha" and a "Beta" value. Omission of the beta value caused a fatal run-time error which was difficult to detect.

Solution: Ensure that all data files contain the information described in this manual.

d) When running a "shrunk" model fit, remember that the shrunk VPA is written to the file "ICA.SHR" and the model parameters written to "ICA.OUT" and displayed by "ICAVIEW" are not changed.

e) Do not have any missing values in the catch-at-age matrix if you are calculating a shrunk VPA.

f) If the ICA1 programme crashes after writing the message F SSQ, then check the following:

- The year range of all the survey data should lie within the year range of the catch at age data plus one year.

- There should be no zeroes in the survey data.
- If an "absolute" catchability model is chosen for any index, then check the units are consistent. If catch numbers are in thousands of fish and catch weights are in kg, then an "absolute" SSB index should be in tonnes.

## 11.0 Summary

This manual was prepared as a general guide to running the Integrated Catch-Age Analysis software. Technical details of the programmes can be found in the Programmers and Technical Reference Manuals. Unfortunately, like most software manuals there are bound to be a few inherent errors or limitations which individual will encounter or identify. We encourage you to notify the authors of any problems you encounter so future versions may be improved.

## 12.0 Acknowledgements

Dr Robin Cook suggested the use of this type of analytical method for pelagic fish and supported the development of these programmes. I am grateful to Dr R. Fryer for his statistical advice, and to Dr M.R. Bravington for the use of his "XYplotW" and "ContourW" object libraries, used in the ICAVIEW, VIEWSRR and VIEWPRO programmes. Dr Per Sparre made a very helpful revision of an early draft of this document.

## 13.0 References

**Anonymous.** 1993a. Report of the workshop on methods of fish stock assessment. Copenhagen, 3-10 February 1993. ICES CM 1993/Assess:12, 86pp.

**Anonymous.** 1993b. Report on the working group on the assessment of demersal stocks in the North Sea and Skagerrak. ICES CM 1993/Assess:6.

**Fournier, D. and Archibald, C.P.** 1982. A general theory for analysing catch at age data. *Canadian Journal of Fisheries and Aquatic Sciences*, **39**, 1195—1207.

## 14.0 Appendix 1: Data File Examples

The example data are taken from the 1995 assessment of North Sea herring. Comments have been added in italic type for improved clarity; they need not be included in the data files.

### *14.1 Example of the stock index file*

Filename: ***NSHERR.NDX***

```
North Sea Herring                    Run title
1                                    Sex code, always = 1
c:\herr_vpa\NSHERRLA.DAT
c:\herr_vpa\NSHERRCN.DAT
c:\herr_vpa\NSHERRCW.DAT
c:\herr_vpa\NSHERRSW.DAT
c:\herr_vpa\NSHERRNM.DAT
c:\herr_vpa\NSHERRMO.DAT
c:\herr_vpa\NSHERRPF.DAT
c:\herr_vpa\NSHERRPM.DAT
```

### *14.2 Example of a commercial landing data file*

Filename: ***NSHERRLA.DAT***

```
NORTH SEA HERRING - LANDINGS (t)
1              1          Sex code, data type (1=landings)
1975           1994       First year, last year of catch-at-age data
0              9          First age, last age
5                         Data format identifier (5=column)
                          Catches by year ...
      312800
      174800
       46000
       11000
       25100
       70764
      174879
      275079
      387202
      409489
      609108
      660553
      773411
      875923
      768886
      619963
      635929
      694206
      647435
      600000
```

## 14.3 Example of a catch-at-age data file

Filename: ***NSHERRCN.DAT***

NORTH SEA HERRING. CATCH NUMBERS AT AGE

| | | |
|---|---|---|
| 1 | 2 | *Sex code, data type (2= catch numbers)* |
| 1975 | 1994 | *First year, last year* |
| 0 | 9 | *First age, last age* |
| 1 | | *Format identifier (1 = matrix)* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 263800 | 2460500 | 541700 | 259600 | 140500 | 57200 | 16100 | 9100 | 3400 | 1400 |
| 238200 | 126600 | 901500 | 117300 | 52000 | 34500 | 6100 | 4400 | 1000 | 400 |
| 256800 | 144300 | 44700 | 186400 | 10800 | 7000 | 4100 | 1500 | 700 | 100 |
| 130000 | 168600 | 4900 | 5700 | 5000 | 300 | 200 | 200 | 200 | 300 |
| 542000 | 159200 | 34100 | 10000 | 10100 | 2100 | 200 | 800 | 600 | 100 |
| 1262700 | 245100 | 134000 | 91800 | 32200 | 21700 | 2300 | 1400 | 400 | 100 |
| 9519700 | 872000 | 284300 | 56900 | 39500 | 28500 | 22700 | 18700 | 5500 | 1100 |
| 11956700 | 1116400 | 299400 | 230100 | 33700 | 14400 | 6800 | 7800 | 3600 | 1100 |
| 13296900 | 2448600 | 573800 | 216400 | 105100 | 26200 | 22800 | 12800 | 11000 | 12100 |
| 6661900 | 1737200 | 1095000 | 421700 | 192500 | 77500 | 21600 | 24100 | 10600 | 17800 |
| 4178900 | 3228200 | 1316200 | 1173400 | 365700 | 123600 | 43300 | 20000 | 13000 | 16000 |
| 3664000 | 4723200 | 1246100 | 827100 | 458300 | 127700 | 61100 | 20200 | 13400 | 14600 |
| 8035500 | 6675400 | 2086900 | 652200 | 456100 | 240000 | 72900 | 23200 | 7800 | 8000 |
| 3122900 | 7762800 | 2202900 | 1076200 | 378600 | 252400 | 126400 | 37500 | 15100 | 8400 |
| 2984000 | 3070000 | 1555200 | 1330900 | 789800 | 206700 | 120700 | 59500 | 19000 | 8500 |
| 1251800 | 2901700 | 864100 | 748600 | 827300 | 372300 | 77100 | 52300 | 27700 | 11400 |
| 2306500 | 2067100 | 1094800 | 538000 | 530500 | 484400 | 198400 | 38000 | 24700 | 12600 |
| 10005700 | 2230500 | 1244400 | 428700 | 350100 | 349100 | 363800 | 147600 | 38000 | 22600 |
| 9892400 | 3687700 | 1133600 | 586900 | 294400 | 207800 | 217800 | 181200 | 84100 | 40200 |
| 4259500 | 1690200 | 1688300 | 463100 | 329100 | 103200 | 86900 | 72300 | 66300 | 44100 |

## 14.4 Example of a catch weight-at-age (kg) data file

Filename: ***NSHERRCW.DAT***

NORTH SEA HERRING - MEAN WEIGHT IN CATCHES

| | | |
|---|---|---|
| 1 | 3 | *Sex code, data type (3 = catch weight)* |
| 1975 | 1994 | *First year, last year* |
| 0 | 9 | *First age, last age* |
| 1 | | *Format identifier (1 = matrix)* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .015 | .05 | .126 | .176 | .211 | .243 | .251 | .267 | .271 | .271 |
| .007 | .049 | .118 | .142 | .189 | .211 | .222 | .267 | .271 | .271 |
| .01 | .059 | .118 | .149 | .179 | .217 | .238 | .265 | .274 | .275 |
| .01 | .059 | .118 | .149 | .179 | .217 | .238 | .265 | .274 | .275 |
| .01 | .059 | .118 | .149 | .179 | .217 | .238 | .265 | .274 | .275 |
| .009 | .036 | .128 | .164 | .194 | .211 | .22 | .258 | .27 | .292 |
| .006 | .067 | .121 | .153 | .182 | .207 | .221 | .238 | .252 | .262 |
| .011 | .035 | .099 | .149 | .18 | .211 | .234 | .258 | .278 | .295 |
| .011 | .055 | .111 | .145 | .174 | .197 | .216 | .237 | .253 | .263 |
| .017 | .043 | .115 | .153 | .173 | .208 | .231 | .247 | .265 | .259 |
| .019 | .055 | .114 | .149 | .177 | .193 | .229 | .236 | .25 | .287 |
| .017 | .058 | .13 | .166 | .184 | .203 | .217 | .235 | .259 | .271 |
| .0099 | .0526 | .103 | .175 | .189 | .207 | .223 | .237 | .249 | .287 |
| .001 | .033 | .115 | .145 | .189 | .204 | .228 | .244 | .256 | .310 |
| .006 | .056 | .130 | .159 | .181 | .214 | .240 | .255 | .273 | .281 |

## 14.5 Example of a stock weight-at-age (kg) data file

Filename: ***NSHERRSW.DAT***

```
NORTH SEA HERRING. STOCK WEIGHTS.
1          4                    Sex code, data type (4= stock weights)
1975       1994                 First year, last year
0          9                    First age, last age
1                               Format identifier (1 = matrix)
 .015   .05   .155   .187   .223   .239   .276   .299   .306   .312
```

## 14.7 Example of a maturity-at-age ogive data file

Filename: ***NSHERRMO.DAT***

```
NORTH SEA HERRING - MATURITY OGIVE
1                   6                   Sex code, data type (6 = maturity ogive)
1975                1994                First year, last year
0                   9                   First age, last age
1                                       Format identifier (1 = matrix)
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0   .82    1   1   1   1   1   1   1
   0   0    .7    1   1   1   1   1   1   1
   0   0   .75    1   1   1   1   1   1   1
   0   0   .63    1   1   1   1   1   1   1
   0   0   .66   .9   1   1   1   1   1   1
   0   0   .79   .94  1   1   1   1   1   1
   0   0   .73   .97  1   1   1   1   1   1
   0   0   .64   .98  1   1   1   1   1   1
   0   0  .513    1   1   1   1   1   1   1
   0   0  .416  .629  1   1   1   1   1   1
   0   0  .721  .858  1   1   1   1   1   1
```

## 14.8 Example of a proportion of F before spawning data file

Filename: ***NSHERRPF.DAT***

```
NORTH SEA HERRING  - PROP. F BEFORE SPAWNING
1                   7                   Sex code, data type (7 = propn of F before spawning)
1975                1994                First year, last year
0                   9                   First age, last age
3                                       Format identifier (3 = scalar)
          .67
```

## 14.9 Example of a proportion of M before spawning data file

Filename: ***NSHERRPM.DAT***

```
NORTH SEA HERRING  - PROP. M BEFORE SPAWNING (ASSUMED, NOT WG)
1                   8                   Sex code, data type (8 = propn of M before spawning)
1975                1994                First year, last year
0                   9                   First age, last age
3                                       Format identifier (3 = scalar)
.75
```

## 14.10 Example of an age-structured tuning data file

Filename: ***NSHERRFL.DAT***

```
NORTH SEA HERRING. TUNING DATA
104                                                    Number of surveys + 100
IYFS Survey Data at ages 2 - 5+                        First survey begins here ...
1983    1995                                           First and last years for this survey
 1       1          0.12          0.14                 Sex code, effort code, start and end of survey (as fractions of year)
 2       5                                             First and last ages for this survey
1       .109e3    .418e2    .141e2    .337e2          Effort value (=1), Data ...
1       .161e3    .747e2    .318e2    .690e1
1       .716e3    .256e3    .262e2    .364e2
1       .661e3    .235e3    .565e2    .172e2
1       .838e3    .117e3    .555e2    .436e2
1       .410e4    .783e3    .554e2    .260e2
1       .775e3    .411e3    .864e2    .100e2
1       .580e3    .322e3    .271e3    .703e2
1       .794e3    .283e3    .250e3    .170e3
1       .377e3    .181e3    .630e2    .102e3
1       .762e3    .236e3    .445e2    .637e2
1       .109e4    .199e3    .636e2    .400e2
1       .128e4    .153e3    .462e2    .930e1
IYFS Survey Data at age 1          The above data structure is repeated for each survey
1979      1995
1           1        0.12          0.14
1          1
1       .172e3
1       .312e3
1       .431e3
1       .772e3
1       .126e4
1       .144e4
1       .208e4
1       .254e4
1       .368e4
1       .453e4
1       .231e4
1       .102e4
1       .116e4
1       .116e4
1       .294e4
1      .1667e4
1      .1188e4
Acoustic Survey Data
1989      1994
1           1        0.54          0.56
2           9
1       .373e7    .375e7    .161e7    .488e6    .281e6    .120e6    .440e5    .220e5
1       .297e7    .353e7    .337e7    .135e7    .395e6    .211e6    .134e6     430e5
1       .283e7    .150e7    .210e7    .198e7    .748e6    .262e6    .112e6    .560e5
1       .418e7    .163e7    .140e7    .151e7    .131e7    .474e6    .155e6    .163e6
1       .371e7    .189e7    .909e6    .795e6    .788e6    .546e6    .178e6    .116e6
1       .328e7    .957e6    .429e6    .363e6    .321e6    .328e6    .220e6    .132e6
MIK Recruitment Index
1978      1995
1           1        0.24          0.26
0           0
1          13.1
1          52.1
1         101.1
1          76.7
1         133.9
1          91.8
1         115.0
1         181.3
1         177.4
1         270.9
1         168.9
1          71.4
1          25.9
1          69.9
1         200.7
1         190.1
1         101.7
1          .127e3
```

## 14.11 Example of an SSB tuning data file

Filename: **NSHERR.RCT**

'HERRING IN NORTH SEA' /

| | | | |
|---|---|---|---|
| | 1 | 10 | 2 |
| ' | YEAR' | 'VPA' | 'LPE' |
| | 1983 | 428 | 635 |
| | 1984 | 726 | 871 |
| | 1985 | 764 | 1022 |
| | 1986 | 818 | 1244 |
| | 1987 | 935 | 699 |
| | 1988 | 1123 | 1249 |
| | 1989 | -11 | 1328 |
| | 1990 | -11 | 1547 |
| | 1991 | -11 | 889 |
| | 1992 | -11 | 860 |

*Number of surveys, Number of years, dummy value always=2*

*The column labelled 'VPA' is not used by ICA but is retained for compatibility with RCT3*

## 14.12 Example of a stock and recruit data file

Filename: **SRR.DAT**

| | |
|---|---|
| 1958 | |
| 1397309 | 34940780 |
| 2601470 | 44713732 |
| 2133604 | 12115316 |
| 1830966 | 108894912 |
| 1239819 | 46320808 |
| 2329719 | 47660696 |
| 2138496 | 62821148 |
| 1527896 | 34899436 |
| 1319586 | 27854342 |
| 929250 | 40260220 |
| 418661 | 38701164 |
| 427025 | 21577270 |
| 377244 | 41067172 |
| 272770 | 32293970 |
| 288985 | 20877350 |
| 233148 | 10010326 |
| 161853 | 21747382 |
| 80204 | 2694527 |
| 76911 | 2647761 |

*Starting year*

*Spawning stock at spawning time (t), Recruits.*

## *14.13 Example of a projection data file*

Filename: **FMULT.DAT**

Fishing Mortality Multipliers for Forwards Projections

| Number of fleets | Number of Years |
|---|---|
| 5 | 10 |

Catch Ratio for each fleet at age in 1994

| Age | Fleet A | Fleet B | Fleet D | Fleet E | Fleet F |
|---|---|---|---|---|---|
| 0 | 0 | 0.729 | 0 | 0.0904 | 0.181 |
| 1 | 0.112 | 0.612 | 0.046 | 0.0919 | 0.115 |
| 2 | 0.577 | 0.106 | 0.160 | 0.0077 | 0.149 |
| 3 | 0.995 | 0.005 | 0 | 0 | 0 |
| 4 | 0.992 | 0.008 | 0 | 0 | 0 |
| 5 | 0.971 | 0.008 | 0 | 0 | 0 |
| 6 | 0.992 | 0.006 | 0 | 0 | 0 |
| 7 | 0.994 | 0.006 | 0 | 0 | 0 |
| 8 | 0.994 | 0.006 | 0 | 0 | 0 |
| 9 | 0.994 | 0.006 | 0 | 0 | 0 |

F Multipliers by year

| | | | | | |
|---|---|---|---|---|---|
| 1995 | 1.0 | 1.0 | 1 | 1 | 1 |
| 1996 | 1.0 | 0.75 | 1 | 1 | 1 |
| 1997 | 1.0 | 0.75 | 1 | 1 | 1 |
| 1998 | 1.0 | 0.75 | 1 | 1 | 1 |
| 1999 | 1.0 | 0.75 | 1 | 1 | 1 |
| 2000 | 1.0 | 0.75 | 1 | 1 | 1 |
| 2001 | 1.0 | 0.75 | 1 | 1 | 1 |
| 2002 | 1.0 | 0.75 | 1 | 1 | 1 |
| 2003 | 1.0 | 0.75 | 1 | 1 | 1 |
| 2004 | 1.0 | 0.75 | 1 | 1 | 1 |

Mean weight at age in the catches of each fleet

| | | | | | |
|---|---|---|---|---|---|
| 0 | 0.007 | 0.006 | 0.0276 | 0.0209 | 0.0142 |
| 1 | 0.084 | 0.040 | 0.086 | 0.0174 | 0.0327 |
| 2 | 0.130 | 0.098 | 0.0925 | 0.0501 | 0.0716 |
| 3 | 0.160 | 0.116 | 0.1 | 1 | 1 |
| 4 | 0.181 | 0.161 | 0.1 | 1 | 1 |
| 5 | 0.215 | 0.196 | 0.1 | 1 | 1 |
| 6 | 0.240 | 0.239 | 0.1 | 1 | 1 |
| 7 | 0.256 | 0.191 | 0.2 | 1 | 1 |
| 8 | 0.276 | 0.240 | 0.2 | 1 | 1 |
| 9 | 0.276 | 0.240 | 0.2 | 1 | 1 |

# 15.0 Appendix 2. Example ICA Output Files

## *15.1 Example of main output file: ICA.OUT*

CATCH NUMBERS AT AGE (Millions)

| | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 264. | 238. | 257. | 130. | 542. | 1263. | 9520. | 11957. | 13297. | 6662. | 4179. | 3664. | 8036. | 3123. | 2984. | 1252. | 2307. | 10006. | 9892. | 4260. |
| 1 | 2461. | 127. | 144. | 169. | 159. | 245. | 872. | 1116. | 2449. | 1737. | 3228. | 4723. | 6675. | 7763. | 3070. | 2902. | 2067. | 2231. | 3688. | 1690. |
| 2 | 542. | 902. | 45. | 5. | 34. | 134. | 284. | 299. | 574. | 1095. | 1316. | 1246. | 2087. | 2203. | 1555. | 864. | 1095. | 1244. | 1134. | 1688. |
| 3 | 260. | 117. | 186. | 6. | 10. | 92. | 57. | 230. | 216. | 422. | 1173. | 827. | 652. | 1076. | 1331. | 749. | 538. | 429. | 587. | 463. |
| 4 | 141. | 52. | 11. | 5. | 10. | 32. | 40. | 34. | 105. | 193. | 366. | 458. | 456. | 379. | 790. | 827. | 531. | 350. | 294. | 329. |
| 5 | 57. | 35. | 7. | 0. | 2. | 22. | 29. | 14. | 26. | 78. | 124. | 128. | 240. | 252. | 207. | 372. | 484. | 349. | 208. | 103. |
| 6 | 16. | 6. | 4. | 0. | 0. | 2. | 23. | 7. | 23. | 22. | 43. | 61. | 73. | 126. | 121. | 77. | 198. | 364. | 218. | 87. |
| 7 | 9. | 4. | 2. | 0. | 1. | 1. | 19. | 8. | 13. | 24. | 20. | 20. | 23. | 38. | 60. | 52. | 38. | 148. | 181. | 72. |
| 8 | 3. | 1. | 1. | 0. | 1. | 0. | 6. | 4. | 11. | 11. | 13. | 13. | 8. | 15. | 19. | 28. | 25. | 38. | 84. | 66. |
| 9 | 1. | 0. | 0. | 0. | 0. | 0. | 1. | 1. | 12. | 18. | 16. | 15. | 8. | 8. | 9. | 11. | 13. | 23. | 40. | 44. |

INDICES OF SPAWNING STOCK BIOMASS

| | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .635E+03 | .871E+03 | .102E+04 | .124E+04 | .699E+03 | .125E+04 | .133E+04 | .155E+04 | .889E+03 | .860E+03 | -.110E+02 |

AGE - STRUCTURED INDICES

INDEX : from 1983 to 1995

| | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | .109E+03 | .161E+03 | .716E+03 | .661E+03 | .838E+03 | .410E+04 | .775E+03 | .580E+03 | .794E+03 | .377E+03 | .762E+03 | .109E+04 | .128E+04 |
| 3 | .418E+02 | .747E+02 | .256E+03 | .235E+03 | .117E+03 | .783E+03 | .411E+03 | .322E+03 | .283E+03 | .181E+03 | .236E+03 | .199E+03 | .153E+03 |
| 4 | .141E+02 | .318E+02 | .262E+02 | .565E+02 | .555E+02 | .554E+02 | .864E+02 | .271E+03 | .250E+03 | .630E+02 | .445E+02 | .636E+02 | .462E+02 |
| 5 | .337E+02 | .690E+01 | .364E+02 | .172E+02 | .436E+02 | .260E+02 | .100E+02 | .703E+02 | .170E+03 | .102E+03 | .637E+02 | .400E+02 | .930E+01 |

INDEX : 2 from 1979 to 1995

| | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .172E+03 | .312E+03 | .431E+03 | .772E+03 | .126E+04 | .144E+04 | .208E+04 | .254E+04 | .368E+04 | .453E+04 | .231E+04 | .102E+04 | .116E+04 | .116E+04 | .294E+04 | .167E+04 | .119E+04 |

INDEX : 3 from 1989 to 1994

| | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|
| 2 | .373E+07 | .297E+07 | .283E+07 | .418E+07 | .371E+07 | .328E+07 |
| 3 | .375E+07 | .353E+07 | .150E+07 | .163E+07 | .189E+07 | .957E+06 |
| 4 | .161E+07 | .337E+07 | .210E+07 | .140E+07 | .909E+06 | .429E+06 |
| 5 | .488E+06 | .135E+07 | .198E+07 | .151E+07 | .795E+06 | .363E+06 |
| 6 | .281E+06 | .395E+06 | .748E+06 | .131E+07 | .788E+06 | .321E+06 |
| 7 | .120E+06 | .211E+06 | .262E+06 | .474E+06 | .546E+06 | .328E+06 |
| 8 | .440E+05 | .134E+06 | .112E+06 | .155E+06 | .178E+06 | .220E+06 |
| 9 | .220E+05 | .430E+05 | .560E+05 | .163E+06 | .116E+06 | .132E+06 |

INDEX : 4 from 1978 to 1995

| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .131E+02 | .521E02 | .101E+03 | .767E+02 | .134E+03 | .918E+02 | .115E+03 | .181E+03 | .177E+03 | .271E+03 | .169E+03 | .714E+02 | .259E+02 | .699E+02 | .201E+03 | .190E+03 | .102E+03 | .127E+03 |

## 15.1 Continued

FISHING MORTALITY

| | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .1510 | .1437 | .0966 | .0450 | .0838 | .1263 | .4853 | .3377 | .4047 | .2188 | .0859 | .0619 | .1616 | .1247 | .1294 | .0557 | .1041 | .1134 | .1346 | .1060 |
| 1 | .6854 | .2372 | .2896 | .1978 | .1647 | .1134 | .2869 | .2273 | .2551 | .1986 | .3827 | .3156 | .3692 | .5892 | .4251 | .4402 | .2907 | .2556 | .3035 | .2391 |
| 2 | 1.2902 | 1.3249 | .2116 | .0235 | .0934 | .3583 | .3249 | .2623 | .3061 | .3037 | .4052 | .4542 | .4023 | .3557 | .4034 | .3627 | .5520 | .4729 | .5616 | .4423 |
| 3 | 1.4984 | 1.3497 | 1.3557 | .0396 | .0644 | .4121 | .2698 | .5103 | .3275 | .4138 | .6685 | .5184 | .4916 | .4001 | .4046 | .3696 | .4322 | .4771 | .5665 | .4463 |
| 4 | 1.3450 | 1.7039 | .3735 | .0962 | .0870 | .2861 | .2962 | .2406 | .4392 | .5131 | .7289 | .5709 | .5753 | .5626 | .5462 | .4490 | .4612 | .6198 | .7360 | .5797 |
| 5 | 1.8072 | 1.4677 | 1.1140 | .0140 | .0481 | .2426 | .3912 | .1498 | .2662 | .5958 | .6449 | .5356 | .5896 | .6451 | .6079 | .4761 | .4568 | .5711 | .6782 | .5342 |
| 6 | 1.2514 | .9271 | .5827 | .0674 | .0105 | .0614 | .3814 | .1352 | .3316 | .3254 | .6981 | .6827 | .5920 | .6300 | .6518 | .4236 | .4451 | .6631 | .7875 | .6203 |
| 7 | 1.9640 | 1.3977 | .5384 | .0438 | .3674 | .0849 | .8339 | .1943 | .3577 | .6131 | .4992 | .7350 | .5301 | .6145 | .6100 | .5804 | .3390 | .6180 | .7339 | .5781 |
| 8 | 1.6778 | 1.3757 | .7725 | .1115 | .1604 | .2817 | .4836 | .3260 | .4060 | .4994 | .7013 | .6516 | .6230 | .6975 | .6446 | .5666 | .5289 | .6198 | .7360 | .5797 |
| 9 | 1.6778 | 1.3757 | .7725 | .1115 | .1604 | .2817 | .4836 | .3260 | .4060 | .4994 | .7013 | .6516 | .6230 | .6975 | .6446 | .5666 | .5289 | .6198 | .7360 | .5797 |

NUMBERS AT AGE (Millions)

| | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2941. | 2783. | 4378. | 4653. | 10590. | 16666. | 37665. | 64208. | 61160. | 52681. | 79714. | 96020. | 84052. | 41722. | 38486. | 36388. | 36608. | 63617. | 52930. | 35514. | 50397. |
| 1 | 7427. | 930. | 887. | 1462. | 1636. | 3583. | 5404. | 8529. | 16851. | 15010. | 15572. | 26910. | 33202. | 26306. | 13550. | 12440. | 12661. | 12136. | 20895. | 17019. | 11750. |
| 2 | 839. | 1377. | 270. | 244. | 441. | 511. | 1177. | 1492. | 2500. | 4803. | 4527. | 3907. | 7220. | 8444. | 5369. | 3258. | 2947. | 3483. | 3458. | 5675. | 4930. |
| 3 | 360. | 171. | 271. | 162. | 177. | 298. | 264. | 630. | 850. | 1364. | 2626. | 2237. | 1838. | 3577. | 4383. | 2657. | 1680. | 1257. | 1608. | 1461. | 2701. |
| 4 | 198. | 66. | 36. | 57. | 127. | 136. | 162. | 165. | 310. | 502. | 738. | 1102. | 1090. | 920. | 1963. | 2394. | 1503. | 893. | 639. | 747. | 766. |
| 5 | 71. | 47. | 11. | 23. | 47. | 106. | 92. | 109. | 118. | 181. | 272. | 322. | 563. | 555. | 474. | 1029. | 1383. | 858. | 435. | 277. | 379. |
| 6 | 23. | 11. | 10. | 3. | 20. | 41. | 75. | 56. | 85. | 81. | 90. | 129. | 171. | 283. | 263. | 234. | 578. | 792. | 438. | 200. | 147. |
| 7 | 11. | 6. | 4. | 5. | 3. | 18. | 35. | 46. | 45. | 55. | 53. | 41. | 59. | 85. | 136. | 124. | 138. | 335. | 369. | 180. | 97. |
| 8 | 4. | 1. | 1. | 2. | 4. | 2. | 15. | 14. | 35. | 28. | 27. | 29. | 18. | 31. | 42. | 67. | 63. | 89. | 164. | 160. | 92. |
| 9 | 2. | 1. | 1. | 1. | 2. | 5. | 5. | 11. | 16. | 30. | 32. | 27. | 26. | 21. | 24. | 31. | 50. | 60. | 73. | 102. | 133. |

STOCK SUMMARY

| Year | Recruits x10^6 | Total B tonnes | Spawn B tonnes | Landings tonnes | Yld/SSB | Ref.F Fbar 2- 6 |
|---|---|---|---|---|---|---|
| 1975 | 2941. | 685359. | 83755. | 312800. | 3.7347 | 1.4384 |
| 1976 | 2783. | 364905. | 80910. | 174800. | 2.1604 | 1.3547 |
| 1977 | 4378. | 217632. | 52031. | 46000. | .8841 | .7275 |
| 1978 | 4653. | 232404. | 69830. | 11000. | .1575 | .0482 |
| 1979 | 10590. | 390159. | 113469. | 25100. | .2212 | .0607 |
| 1980 | 16666. | 638138. | 138565. | 70764. | .5107 | .2721 |
| 1981 | 37665. | 1162068. | 202534. | 174879. | .8635 | .3327 |
| 1982 | 64208. | 1838441. | 284967. | 275079. | .9653 | .2596 |
| 1983 | 61160. | 2455780. | 431834. | 387202. | .8966 | .3341 |
| 1984 | 52681. | 2752338. | 716933. | 409489. | .5712 | .4304 |
| 1985 | 79714. | 3152893. | 734605. | 609108. | .8292 | .6291 |
| 1986 | 96020. | 4064385. | 770129. | 660553. | .8577 | .5524 |
| 1987 | 84052. | 3883050. | 877928. | 773411. | .8810 | .5302 |
| 1988 | 41722. | 3482922. | 1067503. | 875923. | .8205 | .5187 |
| 1989 | 38486. | 3354994. | 1286067. | 768886. | .5979 | .5228 |
| 1990 | 36388. | 3205324. | 1138273. | 619963. | .5447 | .4162 |
| 1991 | 36608. | 3129630. | 993154. | 635929. | .6403 | .4695 |
| 1992 | 63617. | 2956592. | 778008. | 694206. | .8923 | .5608 |
| 1993 | 52930. | 3133569. | 483626. | 647435. | 1.3387 | .6659 |
| 1994 | 35514. | 2900346. | 789956. | 600000. | .7595 | .5246 |

## 15.1 Continued

### PARAMETER ESTIMATES ± SD

| | | | | | |
|---|---|---|---|---|---|
| Separable Model: Reference F by year | | | | | |
| 1 | 1992 | | .6198 | .4917 | .7811 |
| 2 | 1993 | | .7360 | .5779 | .9372 |
| 3 | 1994 | | .5797 | .4317 | .7785 |
| Separable Model: Selection (S) by age | | | | | |
| 4 | 0 | | .1829 | .0357 | .9367 |
| 5 | 1 | | .4124 | .2806 | .6063 |
| 6 | 2 | | .7630 | .5621 | 1.0359 |
| 7 | 3 | | .7698 | .5678 | 1.0436 |
| | 4 | | 1.0000 | Fixed : Reference age | |
| 8 | 5 | | .9215 | .6871 | 1.2360 |
| 9 | 6 | | 1.0700 | .8055 | 1.4213 |
| 10 | 7 | | .9971 | .7497 | 1.3262 |
| | 8 | | 1.0000 | Fixed : last true age | |
| Separable Model: Populations in year 1994 | | | | | |
| 11 | 0 | | 35513644. | 27882302. | 45233673. |
| 12 | 1 | | 17019329. | 13408238. | 21602954. |
| 13 | 2 | | 5674515. | 4537867. | 7095872. |
| 14 | 3 | | 1460872. | 1135453. | 1879554. |
| 15 | 4 | | 747089. | 572700. | 974579. |
| 16 | 5 | | 276814. | 208042. | 368321. |
| 17 | 6 | | 199562. | 146413. | 272004. |
| 18 | 7 | | 180473. | 128955. | 252572. |
| 19 | 8 | | 160459. | 113830. | 226188. |
| Separable Model: Populations at age 8 | | | | | |
| 20 | 1992 | | 89270.9947 | 60503.9247 | 131715.5958 |
| 21 | 1993 | | 163519.5606 | 118482.4423 | 225676.0258 |
| Recruitment in Year 1995 | | | | | |
| 22 | 0 | | 50396609.4946 | 33594387.6858 | 75602456.9432 |
| SSB Index catchabilities | | | | | |
| 23 | 1 | Linear Model : Q | .11784E-02 | .10411E-02 | .13338E-02 |
| Age-structured index catchabilities | | | | | |
| Age-Structured Index 1 | | | | | |
| Linear model fitted. Slopes at age: | | | | | |
| 24 | 2 Q | | .16381E-03 | .13133E-03 | .20432E-03 |
| 25 | 3 Q | | .11045E-03 | .88452E-04 | .13792E-03 |
| 26 | 4 Q | | .70355E-04 | .56288E-04 | .87937E-04 |
| 27 | 5 Q | | .40580E-04 | .32428E-04 | .50782E-04 |
| Age-Structured Index 2 | | | | | |
| Linear model fitted. Slopes at age: | | | | | |
| 28 | 1 Q | | .12311E-03 | .11141E-03 | .13605E-03 |
| Age-Structured Index 3 | | | | | |
| Linear model fitted. Slopes at age: | | | | | |
| 29 | 2 Q | | .13348E+01 | .84486E+00 | .21088E+01 |
| 30 | 3 Q | | .14320E+01 | .90512E+00 | .22655E+01 |
| 31 | 4 Q | | .16265E+01 | .10272E+01 | .25754E+01 |
| 32 | 5 Q | | .20318E+01 | .12809E+01 | .32230E+01 |
| 33 | 6 Q | | .21925E+01 | .13794E+01 | .34850E+01 |
| 34 | 7 Q | | .21527E+01 | .13500E+01 | .34326E+01 |
| 35 | 8 Q | | .21582E+01 | .13447E+01 | .34639E+01 |
| 36 | 9 Q | | .20784E+01 | .12984E+01 | .33271E+01 |
| Age-Structured Index 4 | | | | | |
| Linear model fitted. Slopes at age: | | | | | |
| 37 | 0 Q | | .33227E-05 | .30135E-05 | .36636E-05 |
| Parameters of the B.-H. stock-recruit relationship | | | | | |
| 38 | a | | .6638340E+08 | .5682490E+08 | .7754973E+08 |
| 39 | b | | .5137349E+06 | .3860412E+06 | .6836669E+06 |

RESIDUALS ABOUT THE MODEL FIT

Separable Model Residuals (log(Observed Catch)-log(Expected Catch)) and weights (W) used in the analysis.

| Age | 1992 | 1993 | 1994 | |
|---|---|---|---|---|
| 0 | .83304E+00 | .84239E+00 | .62579E+00 | .10000E-01 |
| 1 | .23309E+00 | .39700E-01 | -.32222E+00 | .50000E+00 |
| 2 | .81350E-01 | -.13813E+00 | -.48282E-01 | .10000E+01 |
| 3 | -.16048E-01 | -.80730E-01 | -.36192E-01 | .10000E+01 |
| 4 | -.11907E+00 | -.78770E-01 | .46072E-01 | .10000E+01 |
| 5 | -.21820E-01 | .14528E-01 | -.59337E-01 | .10000E+01 |
| 6 | -.10247E-01 | -.49425E-01 | -.15184E-01 | .10000E+01 |
| 7 | -.15325E-02 | -.14744E-01 | -.46739E-01 | .10000E+01 |
| 8 | -.37293E-01 | .30673E-01 | -.17958E-01 | .10000E+01 |
| Wts | .10000E+01 | .10000E+01 | .10000E+01 | |

## 15.1 Continued

Biomass Index Residuals: log(Observed Index) - log(Expected Index)

| Idx | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .22141E+00 | .30491E-01 | .16602E+00 | .31536E+00 | -.39208E+00 | -.71479E-02 | -.13208E+00 | .14264E+00 | -.27496E+00 | -.63973E-01 | -.10000E+01 |

Aged Index Residuals: log(Observed Index) - log(Expected Index)

Aged Index

| Age | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | -.12447E+01 | -.15081E+01 | .56535E-01 | .13028E+00 | -.25331E+00 | .11718E+01 | -.34973E-01 | .16925E+00 | .60847E+00 | -.31384E+00 | .40864E+00 | .25574E+00 | .55715E+00 |
| 3 | -.74105E+00 | -.62137E+00 | -.12112E-01 | .43485E-01 | -.46113E+00 | .76195E+00 | -.85133E-01 | .16686E+00 | .50454E+00 | .35331E+00 | .38395E+00 | .29371E+00 | -.58376E+00 |
| 4 | -.36472E+00 | -.24864E-01 | -.57625E+00 | -.22920E+00 | -.23587E+00 | -.69870E-01 | -.38510E+00 | .54682E+00 | .93328E+00 | .96809E-01 | .99058E-01 | .27900E+00 | -.64986E-01 |
| 5 | .10821E+01 | -.71170E+00 | .73417E+00 | -.16551E+00 | .33921E+00 | -.32437E+00 | -.12445E+01 | .22989E+00 | .70975E+00 | .25632E+00 | .16809E+00 | .15690E+00 | -.12210E+01 |

Aged Index 2

| Age | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -.65971E-02 | -.20144E+00 | -.26682E+00 | -.14799E+00 | -.33544E+00 | -.93612E-01 | .26132E+00 | -.94651E-01 | .72956E-01 | .54219E+00 | .51082E+00 | -.21920E+00 |

| 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|
| -.12767E+00 | -.89894E-01 | .30302E+00 | -.67579E-01 | -.35867E-01 |

Aged Index 3

| Age | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|---|
| 2 | -.26605E+00 | -.16938E-01 | .13946E+00 | .31879E+00 | .25553E+00 | -.42861E+00 |
| 3 | -.18251E+00 | .23835E+00 | -.12442E+00 | .27328E+00 | .22415E+00 | -.42661E+00 |
| 4 | -.32935E+00 | .15729E+00 | .15654E+00 | .35954E+00 | .32636E+00 | -.66733E+00 |
| 5 | -.29153E+00 | -.12032E+00 | -.43703E-01 | .22586E+00 | .32308E+00 | -.89059E-01 |
| 6 | -.30705E+00 | .27478E-01 | -.22785E+00 | .13743E+00 | .28951E+00 | .86434E-01 |
| 7 | -.50306E+00 | .13726E+00 | .11238E+00 | -.25533E-01 | .82632E-01 | .20366E+00 |
| 8 | -.30850E+00 | .29087E+00 | .15341E+00 | .17833E+00 | -.22465E+00 | -.79845E-01 |
| 9 | -.39870E+00 | -.42063E-01 | -.27981E+00 | .65704E+00 | .19308E+00 | -.10449E+00 |

Aged Index 4

| Age | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .95650E-01 | .66343E+00 | .88351E+00 | -.11827E+00 | -.13137E+00 | -.44346E+00 | -.11540E+00 | -.10758E+00 | -.32143E+00 | .25995E+00 | .47868E+00 | -.30041E+00 |

| 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|
| -.12768E+01 | -.27796E+00 | .22651E+00 | .36147E+00 | .12785E+00 | .65748E-10 |

PARAMETERS OF THE DISTRIBUTION OF ln CATCHES AT AGE

Separable model fitted from 1992 to 1994

| | | |
|---|---|---|
| Variance | : | .3211 |
| Skewness test statistic | : | 5.3333 |
| Kurtosis test statistic | : | 4.8654 |
| Partial chi-square | : | .1350 |
| Probability of chi-square | : | 1.0000 |
| Degrees of freedom | : | 6 |

## 15.1 Continued

PARAMETERS OF THE DISTRIBUTION OF THE SSB INDICES
DISTRIBUTION STATISTICS FOR ln SSB INDEX 1
Linear catchability relationship assumed.
Last age is a plus-group.

| | | |
|---|---|---|
| Variance | : | .0498 |
| Skewness test statistic | : | -.4612 |
| Kurtosis test statistic | : | -.5505 |
| Partial chi-square | : | .0653 |
| Probability of chi-square | : | 1.0000 |
| Number of observations | : | 10 |
| Degrees of freedom | : | 9 |
| Weight in the analysis | : | 1.0000 |

PARAMETERS OF THE DISTRIBUTION OF THE AGE-STRUCTURED INDICES
DISTRIBUTION STATISTICS FOR ln AGED INDEX 1
Linear catchability relationship assumed.

| | | | | | |
|---|---|---|---|---|---|
| Age | : | 2 | 3 | 4 | 5 |
| Variance | : | .5269 | .2266 | .1665 | .5149 |
| Skewness test stat | : | -1.1037 | -.2875 | 1.2723 | -.7084 |
| Kurtosis test stat | : | .1231 | -.8373 | .2124 | -.4971 |
| Partial chi-square | : | .9758 | .5289 | .4631 | 1.9575 |
| Prob. of chi-square | : | 1.0000 | 1.0000 | 1.0000 | .9995 |
| Number of data | : | 13 | 13 | 13 | 13 |
| Degrees of freedom | : | 12 | 12 | 12 | 12 |
| Weight in analysis | : | .2500 | .2500 | .2500 | .2500 |

DISTRIBUTION STATISTICS FOR ln AGED INDEX 2
Linear catchability relationship assumed.

| | | |
|---|---|---|
| Age | : | 1 |
| Variance | : | .0664 |
| Skewness test stat. | : | 1.6171 |
| Kurtosis test stat. | : | -.1133 |
| Partial chi-square | : | .1448 |
| Prob. of chi-square | : | 1.0000 |
| Number of data | : | 17 |
| Degrees of freedom | : | 16 |
| Weight in analysis | : | 1.0000 |

DISTRIBUTION STATISTICS FOR ln AGED INDEX 3
Linear catchability relationship assumed.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | : | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Variance | : | .0882 | .0825 | .1678 | .0529 | .0514 | .0667 | .0584 | .1438 |
| Skewness test stat. | : | -.3827 | -.3738 | -.7778 | .3226 | -.2489 | -1.4538 | -.1136 | .8211 |
| Kurtosis test stat. | : | -.6718 | -.6926 | -.4795 | -.6010 | -.6368 | .2890 | -.7831 | -.2272 |
| Partial chi-square | : | .0290 | .0288 | .0608 | .0196 | .0194 | .0272 | .0254 | .0647 |
| Prob. of chi-square | : | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | .9999 |
| Number of data | : | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Degrees of freedom | : | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Weight in analysis | : | .1250 | .1250 | .1250 | .1250 | .1250 | .1250 | .1250 | .1250 |

DISTRIBUTION STATISTICS FOR ln AGED INDEX 4
Linear catchability relationship assumed.

| | | |
|---|---|---|
| Age | : | 0 |
| Variance | : | .2282 |
| Skewness test stat. | : | -1.0453 |
| Kurtosis test stat. | : | 1.1344 |
| Partial chi-square | : | .9156 |
| Prob. of chi-square | : | 1.0000 |
| Number of data | : | 18 |
| Degrees of freedom | : | 17 |
| Weight in analysis | : | 1.0000 |

## 15.2 Example of graphics data transfer file: ICA.VIE

```
DATA TRANSFER FILE FOR ICAVIEW
1975    1994  0       9       3       1       4     <— Firstyear, lastyear, firstage, lastage,
LANDINGS BY YEAR                                    No of years to fit selection pattern,
1975                  312800.0000                   No of SSB surveys, No of aged surveys
1976                  174800.0000
1977                   46000.0000
1978                   11000.0000
1979                   25100.0000
1980                   70764.0000
1981                  174879.0000
1982                  275079.0000
1983                  387202.0000
1984                  409489.0000
1985                  609108.0000
1986                  660553.0000
1987                  773411.0000
1988                  875923.0000
1989                  768886.0000
1990                  619963.0000
1991                  635929.0000
1992                  694206.0000
1993                  647435.0000
1994                  600000.0000

FISHING MORTALITY +/- STANDARD DEVIATION
1975       1.4984      -1.0000      -1.0000     -1 indicates the s.d. is not available
1976       1.3497      -1.0000      -1.0000
1977       1.3557      -1.0000      -1.0000
1978        .0396      -1.0000      -1.0000
1979        .0644      -1.0000      -1.0000
1980        .4121      -1.0000      -1.0000
1981        .2698      -1.0000      -1.0000
1982        .5103      -1.0000      -1.0000
1983        .3275      -1.0000      -1.0000
1984        .4138      -1.0000      -1.0000
1985        .6685      -1.0000      -1.0000
1986        .5184      -1.0000      -1.0000
1987        .4916      -1.0000      -1.0000
1988        .4001      -1.0000      -1.0000
1989        .4046      -1.0000      -1.0000
1990        .3696      -1.0000      -1.0000
1991        .4322      -1.0000      -1.0000
1992        .6198       .4917        .7811
1993        .7360       .5779        .9372
1994        .5797       .4317        .7785

RECRUITMENT
1975          2940656.          -1.          -1.
1976          2783076.          -1.          -1.
1977          4378307.          -1.          -1.
1978          4652713.          -1.          -1.
1979         10590152.          -1.          -1.
1980         16666463.          -1.          -1.
1981         37664605.          -1.          -1.
1982         64208280.          -1.          -1.
1983         61159651.          -1.          -1.
1984         52681042.          -1.          -1.
1985         79714046.          -1.          -1.
1986         96019556.          -1.          -1.
1987         84052500.          -1.          -1.
1988         41721944.          -1.          -1.
1989         38485673.          -1.          -1.
1990         36387941.          -1.          -1.
1991         36607978.          -1.          -1.
1992         63616569.          -1.          -1.
1993         52929546.          -1.          -1.
1994         35513645.          -1.          -1.
```

| | | | |
|---|---|---|---|
| 1995 | .50397E+08 | .33594E+08 | .75602E+08 |

TOTAL AND SPAWNING BIOMASS

| | | |
|---|---|---|
| 1975 | 685359. | 83755. |
| 1976 | 364905. | 80910. |
| 1977 | 217632. | 52031. |
| 1978 | 232404. | 69830. |
| 1979 | 390159. | 113469. |
| 1980 | 638138. | 138565. |
| 1981 | 1162068. | 202534. |
| 1982 | 1838441. | 284967. |
| 1983 | 2455780. | 431834. |
| 1984 | 2752338. | 716933. |
| 1985 | 3152893. | 734605. |
| 1986 | 4064385. | 770129. |
| 1987 | 3883050. | 877928. |
| 1988 | 3482922. | 1067503. |
| 1989 | 3354994. | 1286067. |
| 1990 | 3205324. | 1138273. |
| 1991 | 3129630. | 993154. |
| 1992 | 2956592. | 778008. |
| 1993 | 3133569. | 483626. |
| 1994 | 2900346. | 789956. |
| 1995 | 2865938. | 874959. |

## 15.2 Continued

SELECTION PATTERN +/- STANDARD DEVIATION

| | | | |
|---|---|---|---|
| 0 | .18290450 | .03571664 | .93665168 |
| 1 | .41242510 | .28055369 | .60628133 |
| 2 | .76303409 | .56205150 | 1.03588552 |
| 3 | .76977544 | .56782045 | 1.04355915 |
| 4 | 1. | -1. | -1. |
| 5 | .92152809 | .68707723 | 1.23598045 |
| 6 | 1.06998850 | .80554104 | 1.42125023 |
| 7 | .99714120 | .74972201 | 1.32621231 |
| 8 | .10000E+01 | -.10000E+01 | -.10000E+01 |
| 9 | .10000E+01 | -.10000E+01 | -.10000E+01 |

NUMBERS AT AGE AND YEAR

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2940656. | 7427038. | 838635. | 360154. | 197506. | 70893. | 23460. | 10954. | 4335. | 1590. |
| 2783076. | 930163. | 1376734. | 170980. | 65903. | 46560. | 10527. | 6073. | 1391. | 1001. |
| 4378307. | 886827. | 269919. | 271111. | 36299. | 10851. | 9709. | 3769. | 1358. | 547. |
| 4652713. | 1462413. | 244220. | 161833. | 57213. | 22608. | 3223. | 4906. | 1991. | 796. |
| 10590152. | 1636259. | 441440. | 176723. | 127352. | 47018. | 20171. | 2726. | 4249. | 2256. |
| 16666463. | 3582623. | 510533. | 297855. | 135665. | 105636. | 40548. | 18062. | 1708. | 5013. |
| 37664605. | 5403929. | 1176647. | 264326. | 161501. | 92211. | 74992. | 34504. | 15013. | 4589. |
| 64208280. | 8528602. | 1492209. | 629859. | 165242. | 108667. | 56425. | 46340. | 13561. | 10935. |
| 61159651. | 16850533. | 2499695. | 850394. | 309576. | 117539. | 84651. | 44597. | 34526. | 15999. |
| 52681042. | 15010363. | 4803216. | 1363524. | 501823. | 180546. | 81497. | 54976. | 28218. | 30462. |
| 79714046. | 15571707. | 4527235. | 2626423. | 738028. | 271809. | 90038. | 53259. | 26945. | 32224. |
| 96019556. | 26910172. | 3907130. | 2236524. | 1101978. | 322159. | 129045. | 40535. | 29252. | 26552. |
| 84052500. | 33202041. | 7220467. | 1837921. | 1090345. | 563397. | 170617. | 58995. | 17587. | 26318. |
| 41721944. | 26306006. | 8443961. | 3577341. | 920383. | 554970. | 282693. | 85404. | 31418. | 21307. |
| 38485673. | 13549610. | 5368624. | 4383097. | 1963140. | 474484. | 263443. | 136230. | 41801. | 23751. |
| 36387941. | 12439730. | 3258359. | 2656895. | 2394370. | 1028743. | 233779. | 124223. | 66976. | 31134. |
| 36607978. | 12661171. | 2946650. | 1679541. | 1503180. | 1382816. | 578245. | 138480. | 62912. | 50373. |
| 63616569. | 12136365. | 3482873. | 1256885. | 892568. | 857642. | 792382. | 335267. | 89272. | 60399. |
| 52929546. | 20895133. | 3457690. | 1607947. | 638623. | 434563. | 438368. | 369409. | 163521. | 72870. |
| 35513645. | 17019330. | 5674516. | 1460873. | 747090. | 276815. | 199563. | 180474. | 160460. | 102465. |
| 50396609. | 11750355. | 4929606. | 2701049. | 765505. | 378595. | 146808. | 97109. | 91608. | 133240. |

FISHING MORTALITY AT AGE AND YEAR

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .1510283 | .6854134 | 1.2902265 | 1.4983511 | 1.3450258 | 1.8071835 | 1.2514211 | 1.9639511 | 1.6777908 | 1.6777908 |
| .1436628 | .2372370 | 1.3249402 | 1.3497478 | 1.7039207 | 1.4676525 | .9270626 | 1.3976821 | 1.3756739 | 1.3756739 |
| .0965743 | .2895807 | .2115594 | 1.3557429 | .3735035 | 1.1140428 | .5826876 | .5383824 | .7725036 | .7725036 |
| .0450380 | .1978007 | .0234837 | .0396096 | .0962479 | .0140407 | .0673991 | .0437695 | .1114579 | .1114579 |
| .0838292 | .1647135 | .0934370 | .0643954 | .0869521 | .0480512 | .0104729 | .3673804 | .1604003 | .1604003 |
| .1262721 | .1134262 | .3582694 | .4120917 | .2861123 | .2426181 | .0614242 | .0848996 | .2816904 | .2816904 |
| .4852953 | .2868685 | .3249286 | .2697708 | .2962259 | .3911666 | .3813771 | .8338652 | .4836059 | .4836059 |
| .3377499 | .2272567 | .2623131 | .5102937 | .2406473 | .1497509 | .1352446 | .1943028 | .3260170 | .3260170 |
| .4047468 | .2550966 | .3060966 | .3274532 | .4392142 | .2662057 | .3316392 | .3576898 | .4059743 | .4059743 |
| .2188000 | .1986296 | .3036627 | .4138459 | .5131470 | .5957584 | .3254013 | .6130936 | .4994001 | .4994001 |
| .0859414 | .3826524 | .4051882 | .6685166 | .7289366 | .6449422 | .6980653 | .4992035 | .7013031 | .7013031 |
| .0619405 | .3155847 | .4541681 | .5184289 | .5708762 | .5356210 | .6827072 | .7350206 | .6515954 | .6515954 |
| .1616443 | .3691599 | .4023000 | .4916000 | .5753361 | .5896223 | .5920317 | .5300675 | .6230023 | .6230023 |
| .1246695 | .5892255 | .3556959 | .4000742 | .5625621 | .6450780 | .6300152 | .6144692 | .6974535 | .6974535 |
| .1293907 | .4251341 | .4034137 | .4046353 | .5462074 | .6078514 | .6517545 | .6100067 | .6445512 | .6445512 |
| .0556975 | .4402265 | .3627028 | .3695748 | .4489985 | .4760959 | .4236499 | .5803514 | .5666349 | .5666349 |
| .1040599 | .2906824 | .5520325 | .4321739 | .4611513 | .4568340 | .4450688 | .3390391 | .5289373 | .5289373 |
| .1133577 | .2556056 | .4728994 | .4770774 | .6197610 | .5711278 | .6631378 | .6179899 | .6197610 | .6197610 |
| .1346120 | .3035310 | .5615668 | .5665282 | .7359646 | .6782128 | .7874744 | .7338613 | .7359646 | .7359646 |
| .1060336 | .2390907 | .4423450 | .4462530 | .5797177 | .5342267 | .6202919 | .5780610 | .5797177 | .5797177 |
| .1060336 | .2390907 | .4423450 | .4462530 | .5797177 | .5342267 | .6202919 | .5780610 | .5797177 | .5797177 |

## 15.2 Continued

NATURAL MORTALITY AT AGE AND YEAR

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |
| 1.0000000 | 1.0000000 | .3000000 | .2000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 | .1000000 |

BIOMASS INDEX CATCHABILITIES

```
1       1                       .22316650E+00
1       -6.74358677             -6.86746877             -6.61970478
```

AGE STRUCTURED INDEX CATCHABILITIES

```
        2                       5               1.300000000000000E-001  1               1
        .72587265572E+00                        .47604539050E+00        .40807733012E+00        .71757589723E+00
1       2                       -8.716802280620                 -8.937765299520         -8.495839261720
1       3                       -9.110936884097                 -9.333055181424         -8.888818586771
1       4                       -9.561962679362                 -9.785035063240         -9.338890295484
1       5                       -10.112232459173                -10.336493540116        -9.887971378229

        1                       1               1.300000000000000E-001  0       1
        .25770304986E+00
2               1               -9.002418794447                 -9.102317346116         -8.902520242777

        2                       9               5.500000000000000E-001  1       1
.29703482291E+00        .28723280712E+00        .40959239531E+00        .23008670499E+00        .22676809618E+00        .25825801560E+00        .24163893131E+00        .37916043201E+00
    3       2               .288762713639   -.168581785411  .746107212689
    3       3               .359060123457   -.099683892569  .817804139483
    3       4               .486449454839   .026874894840   .946024014838
    3       5               .708936776089   .247554078036   1.170319474141
    3       6               .785038860982   .321623508405   1.248454213559
    3       7               .766705669035   .300079873522   1.233331464548
    3       8               .769273732490   .296146012575   1.242401452406
    3       9               .731615607666   .261127539643   1.202103675689

        0                       0               2.500000000000000E-001  0       1
        .47766740319E+00
    4       0               -12.614738983496        -12.712423139813        -12.517054827179
```

## 15.3 Example of ICA.AV file: Analysis of Variance

Total weighted SSQ is : 25.749456860796600

Unweighted Residuals About the Model fit

| | Start SSQ | End SSQ | df | Variance | IV Wt |
|---|---|---|---|---|---|
| Separable model: | .4992 | 4.2151 | 6 | .7025 | 1.42346 |
| Biomass idx 1 | .4784608 | .4482327 | 9 | .0498 | 14.10564 |
| Aged index 1 | 18.1666534 | 17.2194431 | 48 | .3587 | 1.95829 |
| Aged index 2 | 1.1106787 | 1.0625748 | 16 | .0664 | 10.57826 |
| Aged index 3 | 6.0552748 | 3.5586980 | 40 | .0890 | 7.89629 |
| Aged index 4 | 4.1329832 | 3.8788250 | 17 | .2282 | 3.07895 |

Partition of the weighted residuals

Catch at Age Matrix :.1685E+00 for 27 observations.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SSB Index | 14.482327E-01 | 10 | | | | | | |
| | | | | | | | | |
| Aged Index | 1 | | | | | | | |
| Age: | 2 | 3 | 4 | 5 | | | | |
| Wted SSQ: | .1581E+01 | .6799E+00 | .4996E+00 | .1545E+01 | | | | |
| No data: | 13 | 13 | 13 | 13 | | | | |
| Aged Index | 2 | | | | | | | |
| Age: | 1 | | | | | | | |
| Wted SSQ: | .1063E+01 | | | | | | | |
| No data: | 17 | | | | | | | |
| Aged Index | 3 | | | | | | | |
| Age: | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Wted SSQ: | .5514E-01 | .5156E-01 | .1049E+00 | .3309E-01 | .3214E-01 | .4169E-01 | .3650E-01 | .8986E-01 |
| No data: | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Aged Index | 4 | | | | | | | |
| Age: | 0 | | | | | | | |
| Wted SSQ: | .3879E+01 | | | | | | | |
| No data: | 18 | | | | | | | |

# 16.0 Appendix 3. Example Graphical Output

## *16.1 Example output from ICAVIEW*

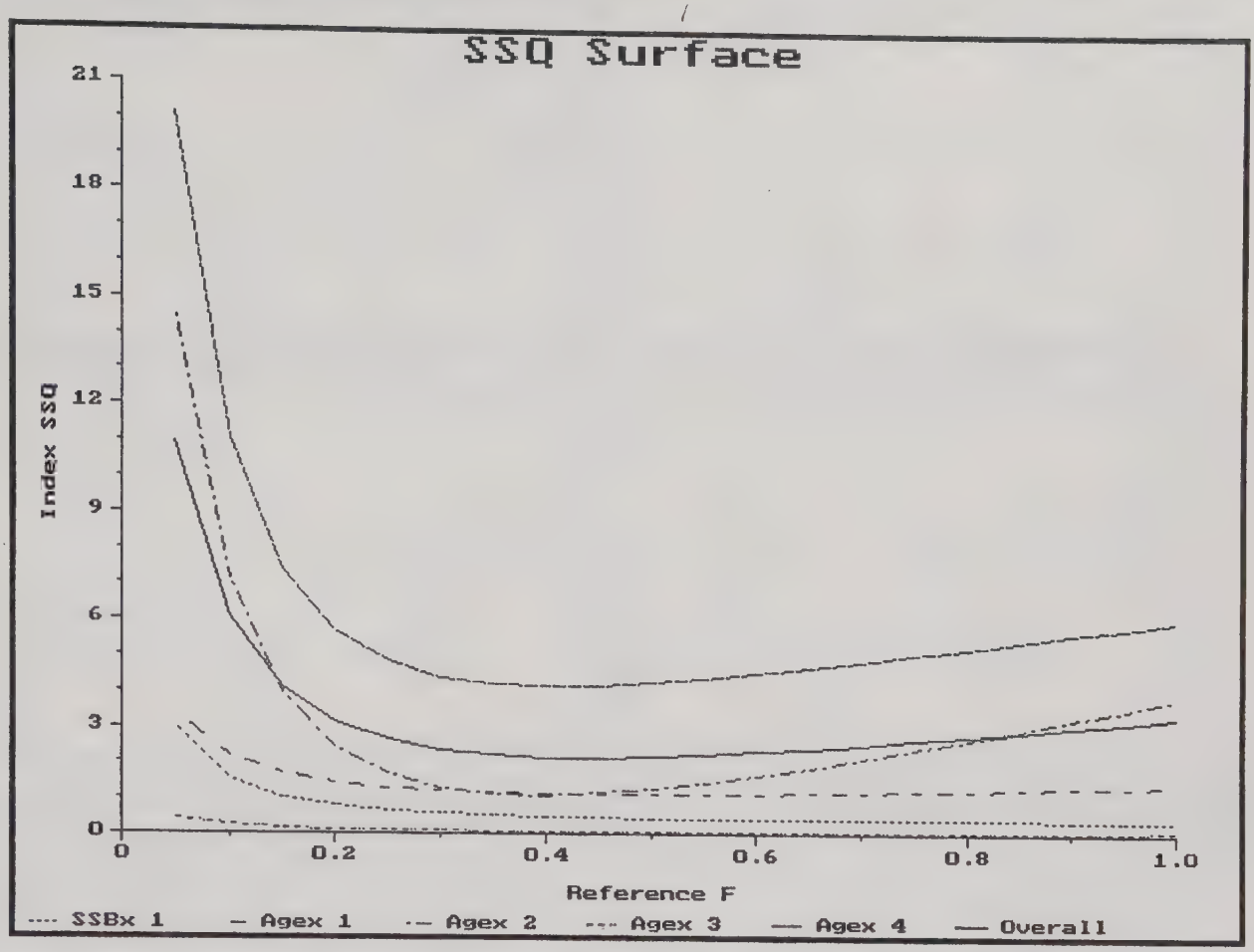


Figure 16.1.1. Graph generated by ICAVIEW. Unweighted sums of squared residuals for each index are plotted against the fishing mortality at reference age for 20 separable VPA fits over a user-specified range of fishing mortalities. This diagnostic graph can be used to detect differences in the fishing mortality predictions from different index series. In this example, the SSB index (labelled SSBx 1) indicates a fishing mortality around 0.7 whereas the third aged index (labelled Agex 3) indicates a fishing mortality around 0.3.

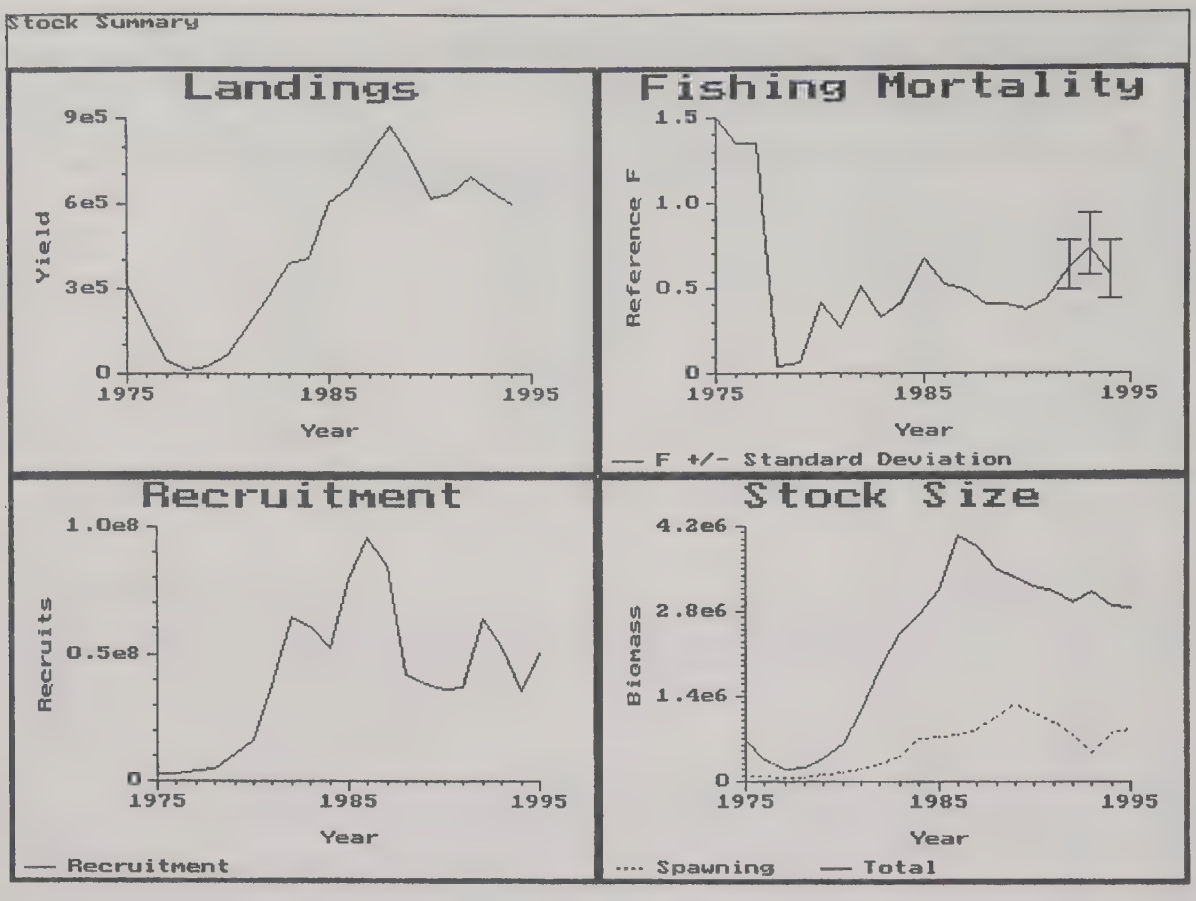


Figure 16.1.2. Graph generated by ICAVIEW. Summary of the stock assessment. Clockwise from top left: 1) Landings by year in tonnes; 2) Fishing mortality at reference age ± standard deviation; 3) Total and spawning stock biomasses; 4) Recruitment.

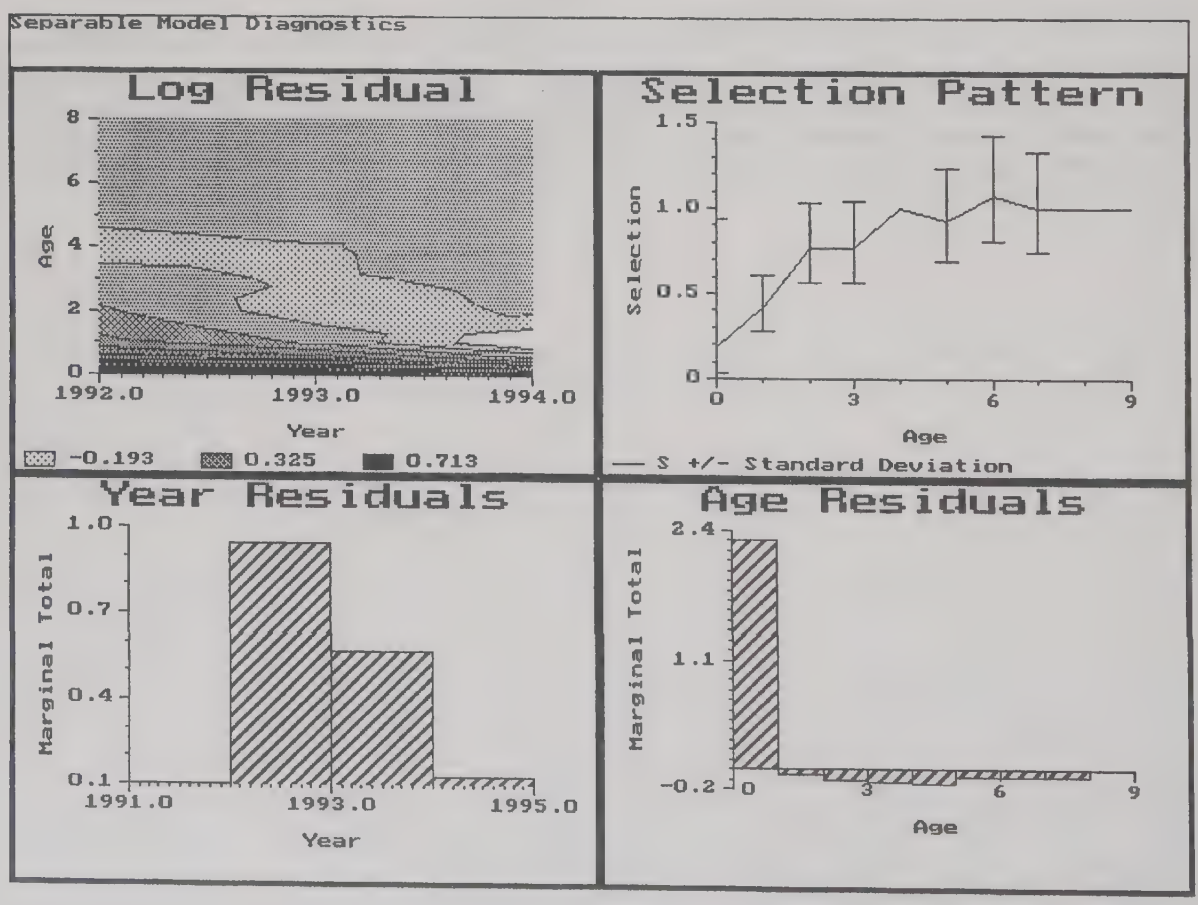


Figure 16.1.3. Graph generated by ICAVIEW. Separable model diagnostics: 1) Contour plot of catch residuals against the separable model by year and age; 2) Selection at age ± standard deviation; 3) and 4) Year and age marginal totals respectively.

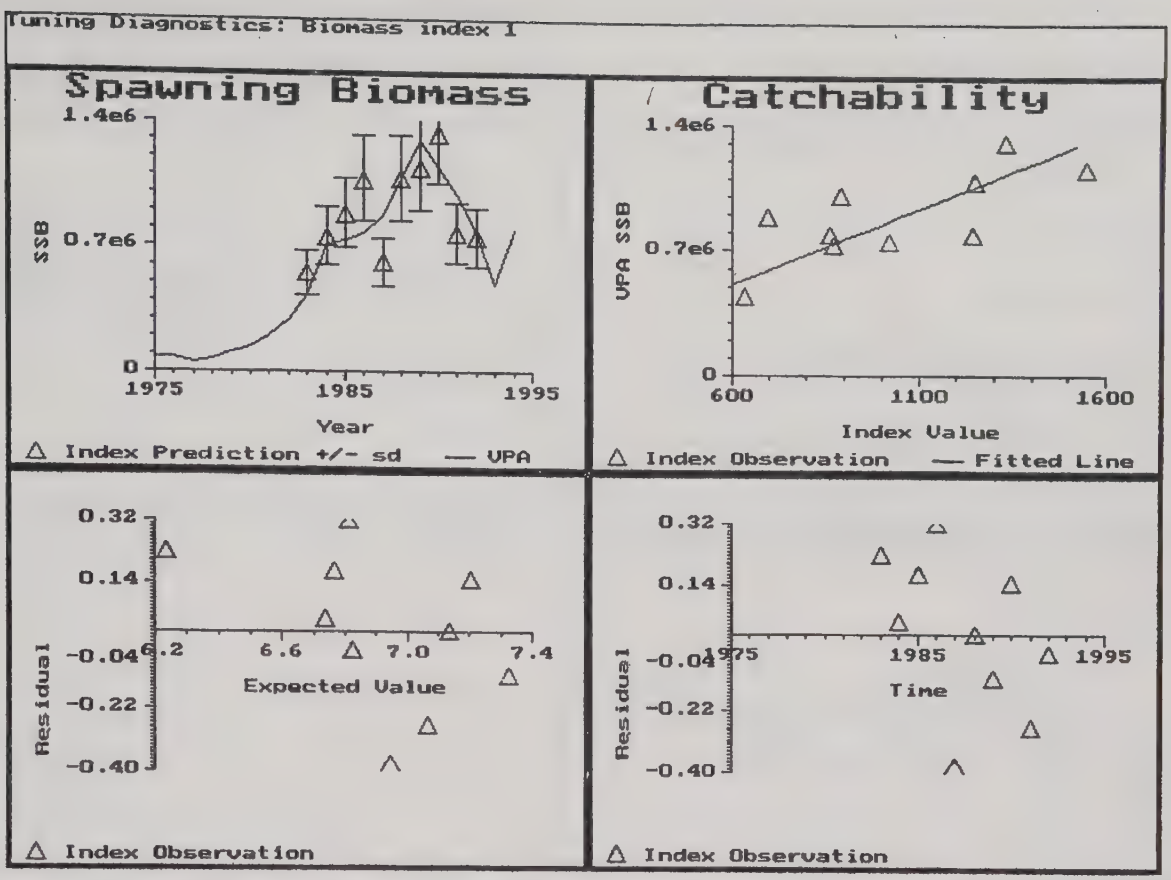


Figure 16.1.4. Graph generated by ICAVIEW. Fitting diagnostics for the index of spawning biomass, which in this example is the "Larval Production Estimate" for North Sea herring. A linear catchability model is fitted. Clockwise from top left: 1) Stock size and index prediction; 2) Estimated SSB, observed index values and the relation fitted; 3) Log residual and log expected values for the catchability model fit; 4) Log residual plotted on time.

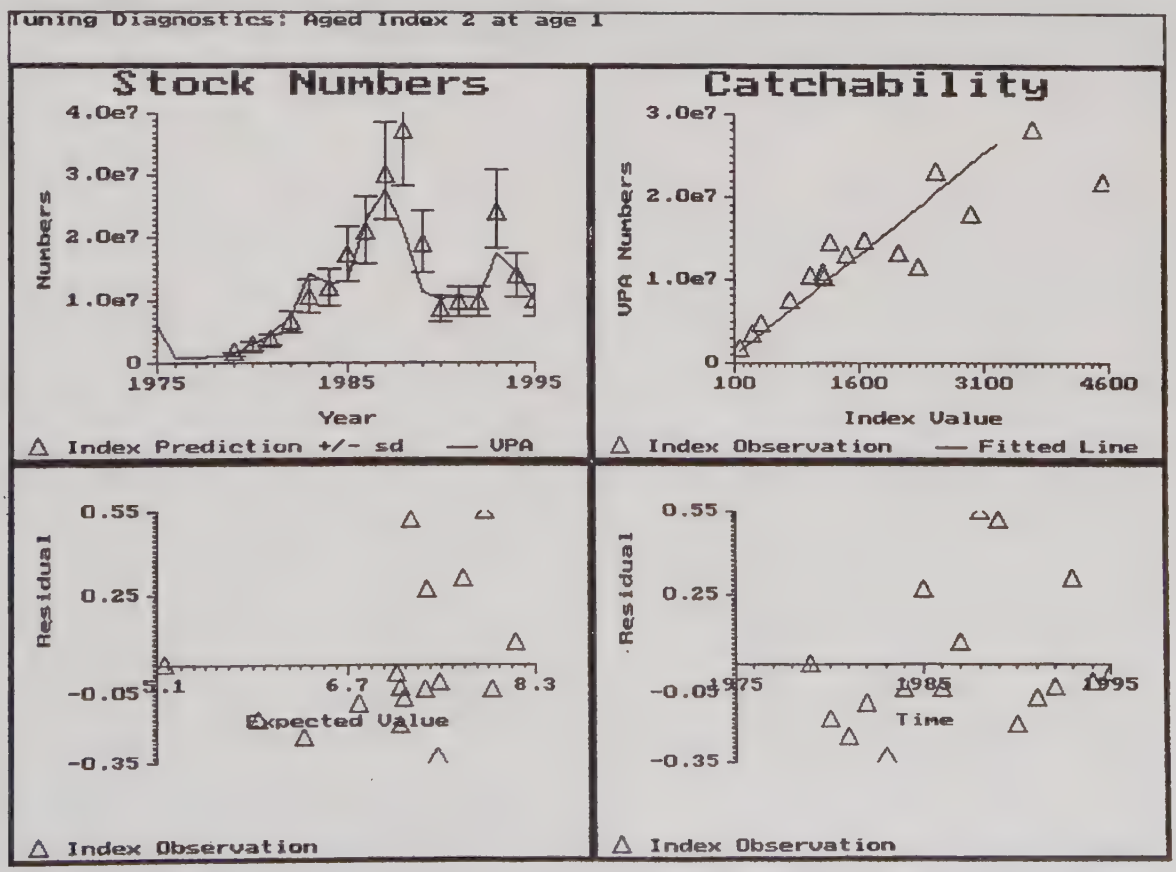


Figure 16.1.5. Graph generated by ICAVIEW. Example fitting diagnostics for one age of an age-structured index (here, the IBTS estimate of the relative abundance of 1-ring herring). One of these graphs is drawn for each age of each age-structured index. A linear catchability model is fitted. Clockwise from top left: 1) Stock size and index prediction; 2) Estimated stock size of one-ringers, observed index values and the relation fitted; 3) Log residual and log expected values for the catchability model fit; 4) Log residual plotted on time.

## 16.2 Example output from VIEWSRR

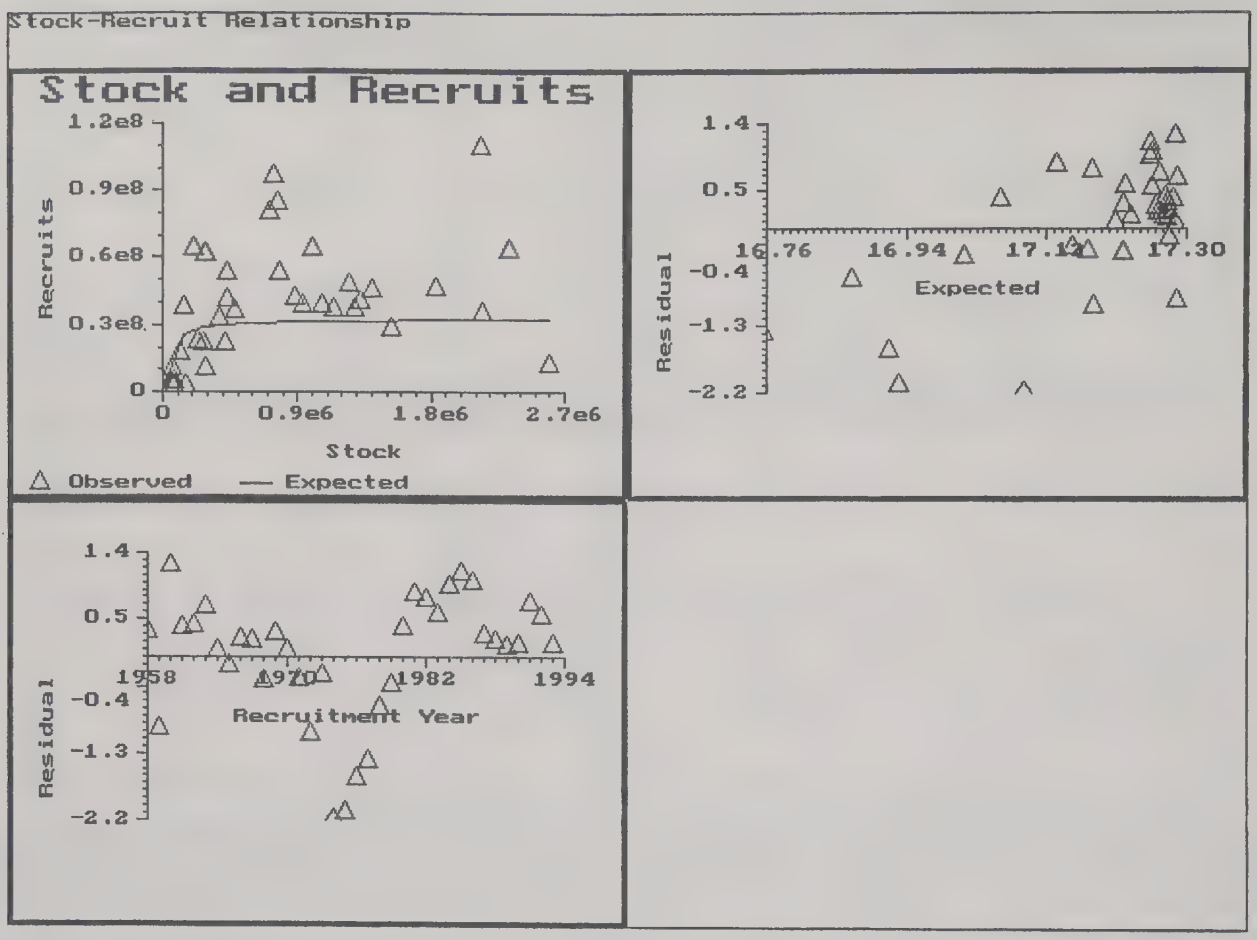


Figure 16.2.1. Graph generated by VIEWSRR. Graphs show 1) the fitted line and estimates of spawning stock and corresponding recruitment; 2) plot of residual on expected value; 3) a plot of residuals on time.

## 16.3 Example output from VIEWPRO

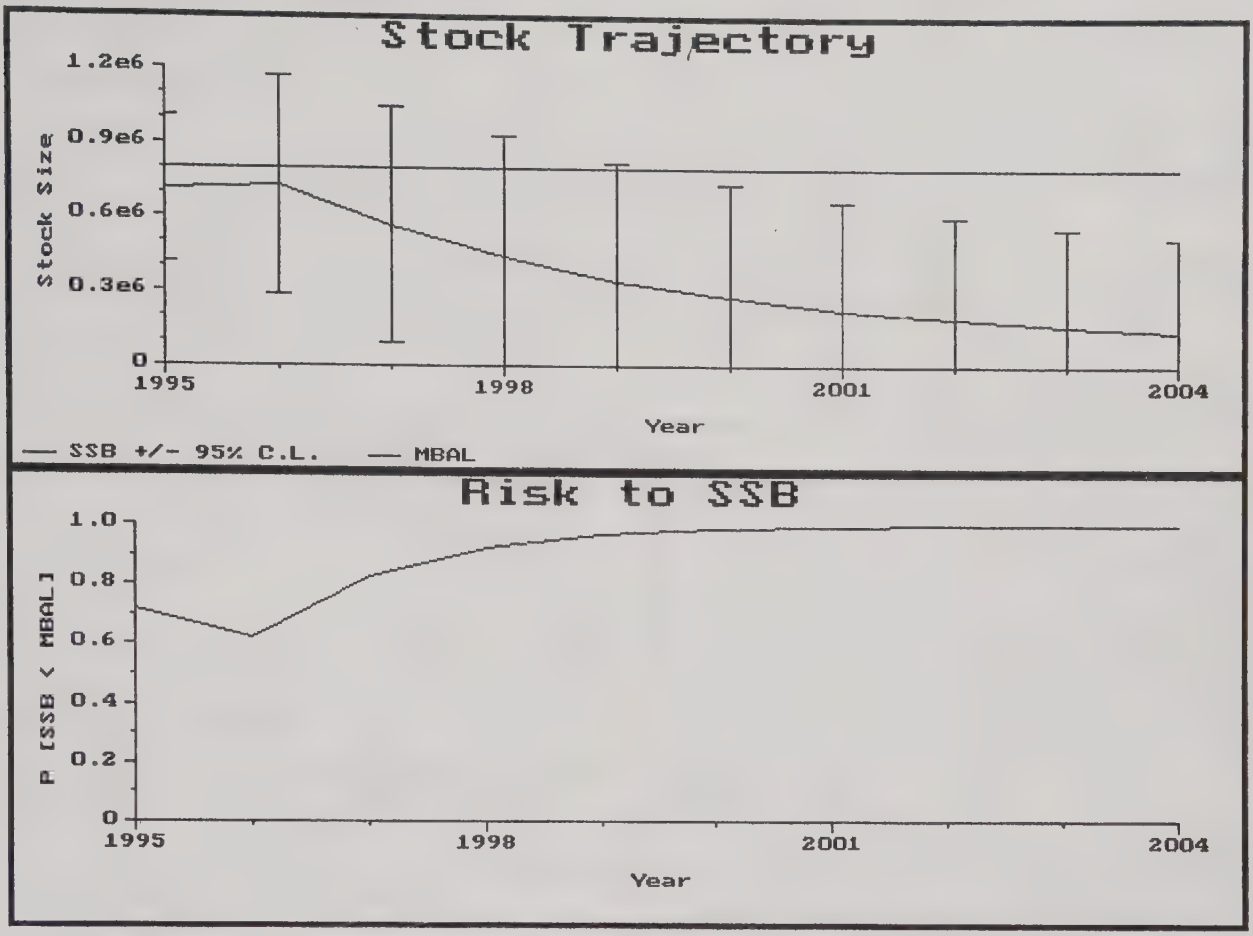


Figure 16.3.1. Graph generated by VIEWPRO. Example projection based on North Sea herring, using the fleet F multipliers given in Table 14.10. Upper: spawning stock size ± 95% confidence limits, and the minimum biological acceptable stock size (MBAL). Lower: risk of projection option, as the estimated probability that the stock size will fall below MBAL in any given year.

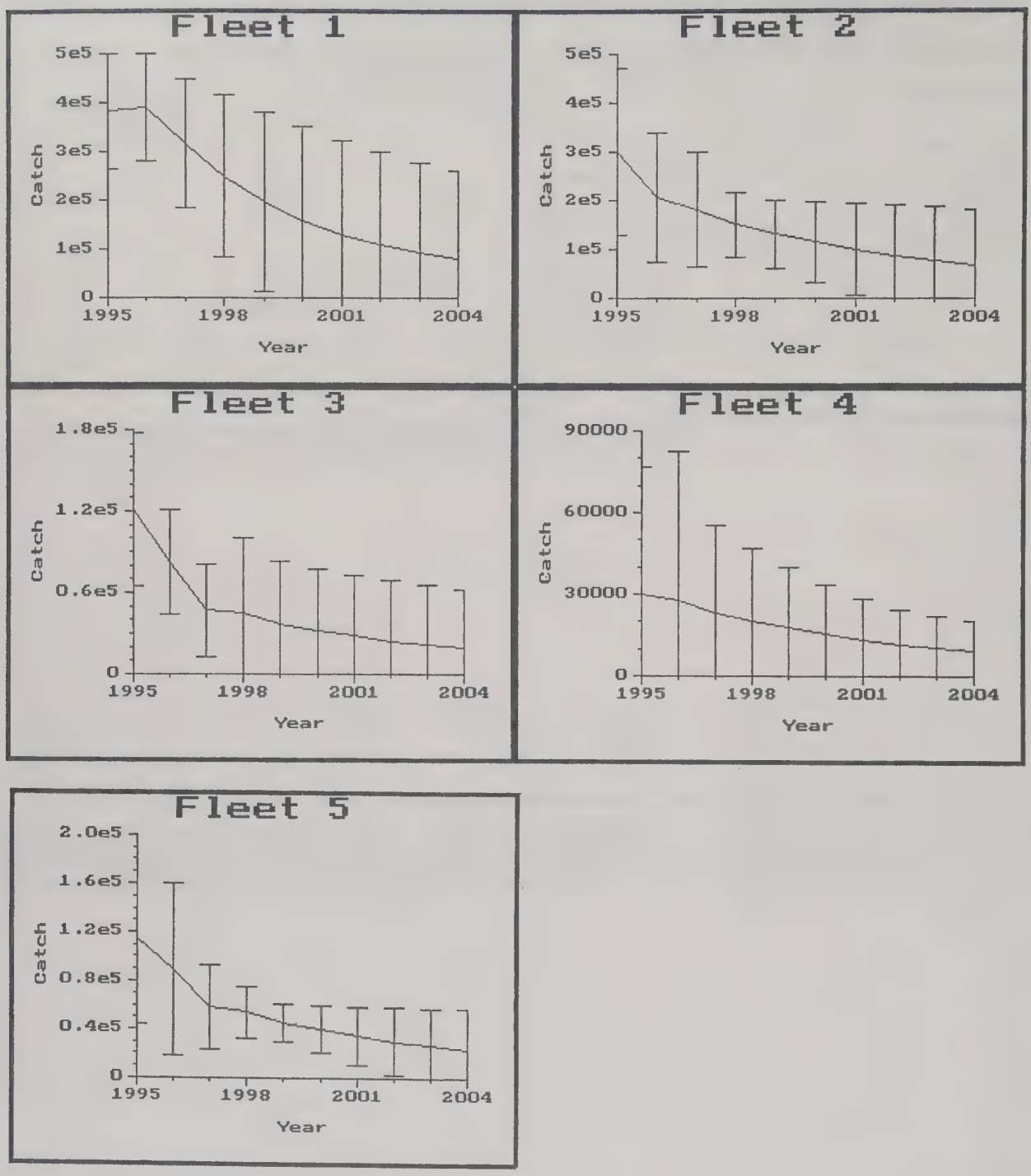





Figure 16.3.2. Graph generated by VIEWPRO. Example projection based on North Sea herring, using the F-multipliers given in Table 14.10. Estimated catches by fleet, ± 95% confidence limits.

## Section B. Technical Reference

# 1.0 General

## 1.1 Introduction

The ICA programmes are intended to provide a method for analysing time-series of catch-at-age and research vessel survey information. They provide a convenient implementation of a method which has been described by Deriso *et al.* (1985). Some of the properties of the model have been discussed by Kimura (1986) and Gudmundsson (1986). The user should refer to these documents for a detailed account of the method. The distinguishing features of this implementation are:

a) Survey data may be either as age-structured indices or as indices of spawning biomass.

b) The relationship between survey index and stock abundance may be either :

- identity, where an absolute measure of stock size is estimated;
- proportionate, where the index is assumed to bear a linear relationship to stock abundance;
- power, where the index is assumed to bear a power-law relation to stock abundance.

c) Separability in the catches at age is assumed.

d) Assignation of statistical weights to the various data types may be either by the user, if these are known from internal sources or if they are to be assigned arbitrary values, or they may be assigned using an iterated inverse-variance reweighting scheme.

An advantage of this type of model is that approximate estimates of the variance of many of the estimated parameters of interest can be calculated. As a well-defined model is fitted to the data, a number of conventional statistics such as measures of goodness-of-fit can be calculated, and an assessment can be made of the extent to which the data conform to the assumptions of the model.

## 1.2 The Deriso-Gudmundsson-Kimura Model

The model is a simplified derivative of the general model described by Fournier and Archibald (1982) in which the model is fitted by simple nonlinear least squares. Variables are defined on page 52.

In its simplest form the model may be thought of as a mimisation of:

$$\sum \lambda_C (C-\hat{C})^2 + \sum \lambda_i (I-\hat{I})^2 \qquad (1)$$

where C are the catch at age observations; $\hat{C}$ are the catches at age that are predicted by the model; I are the index observations and $\hat{I}$ are the index observations that are predicted by the model. Internally the catches at age are assumed to be linked by the usual catch equations; the index series and the stock sizes are linked by one of three catchability models.

The various parameters of interest such as cohort strengths and fishing mortalities are estimated by minimising the term in equation (1). Actual observations of catch and abundance index are compared directly with the predictions of the entire model so that the parameters that best explain the observed data will be found.

The first term in the model represents a separable constraint. Fitting a separable VPA with no tuning series is equivalent to minimising the first term in Eqn 1.2.1. The second term in the model represents the tuning of the separable VPA to the index series. The indices may represent numbers at age or spawning stock size.

Additional terms may be included in the model to allow estimation of stock-recruit relations etc.

## 1.3 Prior assumptions

The following principal prior basic assumptions are made in the model:

(1) Indices of abundance are related to stock size according to the specified catchability model.

(2) Indices are unbiassed and errors are

uncorrelated. Catchability is assumed constant with time.

(3) The usual VPA assumptions about stock unity, migration and mortality rates apply.

(4) Selection pattern is assumed constant ie $F_{a,y} = S_a F S_y$.

(5) Errors are lognormally - distributed; variance is constant with time.

(6) Optionally, that recruitment depends on spawning stock size according to the relation described by Beverton and Holt (1957).

Appropriate use of the model depends on these assumptions not being violated.

## 1.4 Treatment of errors in the catches at age

Catches at age are assumed to be measured with an error that has an independent lognormal distribution. The estimates of the population sizes that are calculated in fitting the model are the least-squares estimates appropriate to the specified model structure. In contrast, in a conventional VPA (As in XSA and ADAPT) it is assumed that the catches at age are measured without error, and the population sizes are then reconstructed along a cohort. The two assumptions about errors in the catches at age lead to different estimates of mortalities and cohort strengths. Estimates of population sizes made using the two methods are not necessarily reconcilable: terminal population sizes estimated using the least-squares method may not be consistent with a "conventional" VPA. For example, consider the case where catches at age are measured with substantial error, particularly at the oldest ages. A least-squares method will yield estimates of population size that are most consistent with the estimated catches and with the index data over the entire cohort; it can happen that the resulting estimate of final population size may be lower than the estimated catch at the oldest age. In such a case, an attempt to recalculate a conventional VPA from the terminal populations estimated using the model will cause a numerical error. This problem is also discussed by Shepherd (1992), who refers to it as a "negative survivors" problem.

Various authors have dealt with this problem in different ways. Shepherd's (op cit.) answer has been to treat the catches as precise throughout; but he recognises that this simplification is not always desirable. Gudmundsson (1986) used a weighted mean between the fitted population and the "conventional" VPA, but the weighting factor used was arbitrarily chosen. The choice taken here has been to use the fitted populations as the best available estimates of population size and age in the period for which the separable model is fitted. In earlier years, a "conventional" VPA initiated with the populations in the first year for which the separable model is fitted has been used. This makes the model internally consistent over the period of fitting the separable constraint. Earlier years are treated in a simplistic fashion on account of their lesser importance for management purposes, and in order to decrease the number of parameters that need to be estimated.

It remains somewhat unrealistic to assume that the errors in the catches at age are uncorrelated. Fournier and Archibald (1982) described a model with a more realistic error structure in which the errors in estimating total catch are considered independently from the errors in estimating the ageing errors. This approach is appealing, but does not seem to have yet gained general acceptance. In future implementations of this type, one might wish to move towards either an approach of the Fournier and Archibald type, or else to abandon the assumption of uncorrelated errors in the catch at age data and instead to attempt to estimate the matrix of variances and covariances for the catches at age.

## 1.5 Shrinkage

Use of shrinkage in stock assessments has been found helpful in some circumstances (Anon., 1993). An option has been included in the programmes to generate a "shrunk" VPA based on the model fit. Although conceptually similar, the implementation is quite different to

that used by Anon. (1993), so that their advice on appropriate levels of "minimum s.e. of the mean" are not applicable here.

## 2.0 Implementation

### *2.1 Overview and purpose*

The software package named "Integrated Catch-Age analysis" (ICA) has been written to provide a tool which allows a variety of model choices described in section 1 to be implemented conveniently.

The programme allows a statistical analysis of an age-structured data set to be completed simply and relatively quickly, so that the uncertainties inherent in a stock assessment can be assessed and the consistency of an assessment can be evaluated. It allows estimates to be calculated of the standard deviation of the estimated fishing mortalities, and of other parameters of management interest. A post-processing programme displays a series of graphs of the parameter estimates: fishing mortality, recruitment, etc, with error bars where appropriate. Residual plots are also drawn. These allow a visual assessment of the consistency of a model fit to be made simply and quickly. A post-processing projection programme allows calculation of stock projections, with associated estimates of error and risk.

A number of diagnostic plots are provided in order that the user may check that the data conform reasonably to the assumptions in Section 1.3. Test statistics for goodness of fit, skewness and kurtosis are provided.

### 2.2 The programmes

#### *2.2.1 ICA1.EXE: Initialisation*

This programme performs the functions preparatory to the least-squares analysis proper. The data files are read, appropriate parameter choices are requested from the user on the screen, and an initial estimate of the minimum is found. Over a range of terminal fishing mortalities specified by the user, the sum of squared residuals for each index series is calculated. A simple one-dimensional minimisation method is then used to find the terminal F corresponding to the lowest sum of squared residuals in the separable VPA.

ICA1 estimates fishing mortality at reference age by performing a minimisation of

$$\sum_a \sum_y \sum_A (\ln(I_{a,y,A}) - \ln(\hat{I}_{a,y,A}) + \sum_y \sum_B (\ln(I_{y,B}) - \ln(\hat{I}_{y,B}) \quad (2)$$

where the $\hat{I}$ are generated using the specified catchability models,

$$\hat{I}_{y,B} = g_B(S\hat{S}B_y) \quad ; \quad \hat{I}_{a,y,A} = h_A(N_{a,y,A}, PZ_A) \quad (3)$$

SSB is estimated from the VPA populations, weights at age, and maturity ogives:

$$S\hat{S}B_y = \sum_a N_{a,y} W_{a,y} O_{a,y} \exp(-(F_{a,y} PF + M_{a,y} PM)) \quad (4)$$

where $g_B(S\hat{S}B)$ may take one of three forms:

$$\begin{aligned} \hat{I}_y &= S\hat{S}B && \text{[Identity Model]} \\ \hat{I}_y &= Q_B.S\hat{S}B_y && \text{[Linear Model]} \\ \hat{I}_y &= Q_B.S\hat{S}B_y^{K_B} && \text{[Power Model]} \end{aligned} \quad (5)$$

similarly, $h_A(N_{a,y}, PZ_A)$ may take one of three forms:

$$\begin{aligned} \hat{I}_{a,y,A} &= N_{a,y}.\exp(-(F_{a,y}+M_{a,y}).PZ_A) && \text{[Identity Model]} \\ \hat{I}_{a,y,A} &= Q_{a,A}.N_{a,y}.\exp(-(F_{a,y}+M_{a,y}).PZ_A) && \text{[Proportionate Model]} \\ \hat{I}_{a,y,A} &= Q_{A,a}.(N_{a,y}.\exp(-(F_{a,y}+M_{a,y}).PZ_A) && \text{[Power Model]} \end{aligned} \quad (6)$$

The catchability parameters Q and K are calculated from simple regressions (where necessary) of I against population size, against a VPA in which

$$\sum_a \sum_y (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2 \quad (7)$$

where

$$\hat{C}_{a,y} = FS_y.S_a.\bar{N}_{a,y}$$

where (8)

$$\bar{N}_{a,y} = \frac{N_{a,y}(1-\exp(-FS_y.S_a - M_{a,y})}{FS_y.S_a + M_{a,y}}$$

has previously been minimised by the method of Pope and Shepherd (1982). If a Beverton and Holt stock-recruit relation is to be fitted, starting parameters a and b are found by a linear regression of:

$$\frac{\hat{SSB}_y}{R_y} = \frac{b}{a} + \frac{1}{a}\hat{SSB}_y \qquad (9)$$

where b/a and 1/a are the intercept and slope of the regression. The method is explained by Hilborn and Walters (1992).

### 2.2.2 *ICA2.EXE: Model fitting, reweighting and shrinkage*

This programme performs the multidimensional minimisation, reweighting and output functions. The programme initially accepts the users' choice as to whether or not to recalculate weights and variances iteratively. The next parameter to be input is the estimate of internal correlation of the errors in each age-structured index (see $\alpha$ in Eqn 14). The user must also specify a stopping criterion for the reweighting iterations.

The programme performs a nonlinear minimisation of

$$\begin{aligned}&\sum_{a,y} \lambda_{a,y} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2 + \\ &\sum_{b,y} \lambda_B (\ln(I_{y,B}) - \ln(\hat{I}_{y,B}))^2 + \\ &\sum_{a,y,A} \lambda_{a,A} (\ln(I_{i,a,y}) - \ln(\hat{I}_{a,y,A}))^2\end{aligned} \qquad (10)$$

where the predicted catches and index values are related to the fitted population sizes as given in Eqns 3-6 and 8.

Elements of N are assumed related as:

$$N_{a+1,y+1} = N_{a,y}.\exp(-FS_y.S_a - M_{a,y}) \qquad (11)$$

If a stock-recruit model is to be fitted, an additional term is included in the minimisation:

$$\lambda_{srr} \sum_y (\ln(R_y) - \ln(\frac{a\ \hat{SSB}_y}{b + \hat{SSB}_y}))^2 \qquad (12)$$

Note that this approach is not strictly correct; $SSB_y$ and $R_y$ are treated as data although they are of course quantities estimated elsewhere in the model. This is unavoidable unless the problem were to be reformulated in a new and unconventional manner, which for the moment has been eschewed.

The parameters estimated by the model are:

- Population sizes N for all true ages in the last year, and for the last true age in the years for which the separable model is to be fitted.
- Population size N for the first true age (ie recruitment) in the year succeeding the last year for which there are catch-at-age observations, if there is a survey observation that allows this forthcoming recruitment to be estimated.
- Other population sizes are estimated from Eqn 11.
- Fishing mortality at reference age FS for each year in which the separable model is fitted.
- Selection S at each true age, except for the reference age and for the last true age.

  Catchability parameters Q and K as specified for each index.

  Parameters a and b of the Beverton and Holt stock-recruit relationship (if fitted).

Parameters assumed as fixed and measured without error are:

- Natural mortality
- Weights at age in the stock
- Maturity ogives
- Proportions of annual F, M and Z before spawning and before each age-structured survey (PF, PM, PZ).

Where the option to recalculate all weights iteratively is used, these are calculated as

$$\lambda_B = \frac{\sigma_C^2}{\sigma_B^2} \qquad (13)$$

for the indices of SSB, and as

$$\lambda_{A,a} = \frac{(\alpha_A (1-k_A) + 1)}{k_A} \times \frac{\sigma_C^2}{\sigma_{A,a}^2} \qquad (14)$$

for the age-structured indices._ is a user-specified parameter indicating the extent of the correlation of the errors in the age-structured survey index observations at different ages in the same years. Here,

$$\sigma_c^2 = \frac{1}{df_C} \sum_{a,y} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y}))^2$$

$$\sigma_B^2 = \frac{1}{df_B} \sum_{y} (\ln(I_{B,y}) - g_B(\hat{SSB}_y))^2 \quad (15)$$

$$\sigma_{a,A}^2 = \frac{1}{df_{a,A}} \sum_{y} (\ln(I_{a,y,A}) - \ln(\hat{I}_{a,y,A}))$$

where

$$df_C = \text{Number of catch at age obervations} - \text{Number of N, S, F parameters fitted for the separable model} \quad (16)$$

$$df_B = \text{Number of SSB index observations} - \text{Number of } Q_B, K_B \text{ parameters fitted} \quad (17)$$

$$df_{a,A} = \text{Number of observations of } I_{a,A} - \text{Number of } Q_{a,A}, K_{a,A} \text{ parameters fitted} \quad (18)$$

$\lambda_{srr}$ are calculated in an analogous fashion.

A shrunk estimator can be considered as a weighted average of a parameter estimate obtained from a complex model and that obtained from a much simpler model. It is assumed that the complex model affords a good representation of the structure of the data and therefore returns an unbiased, though highly variable parameter estimate. The simpler model provides an estimator which is less variable but is biased. Using a shrunk estimator is an attempt at combining the useful properties of the two estimators. Let the simple estimator be a straightforward arithmetic mean ($Y_{AM}$), and denote the estimator from the complex model as $Y_{model}$. The shrunk estimator $Y_{SH}$ is then :

$$Y_{SH} = ( 1 - \theta ) Y_{AM} + \theta . Y_{model} \quad (19)$$

A very simple approach has been used here to calculate a "shrunk VPA" as follows:

(1) The complex model in question is that fitted by the ICA2 programme;

(2) Catches at age are here considered precise, as is usual in VPA calculations

(3) The shrunk parameters, $Y_{SH}$ are the log fishing mortalities at each age in the last year used to initiate the VPA

(4) The F from the model is calculated as:

$$F_{a,y} = FS_y . S_a \quad (20)$$

(5) An arithmetic mean of ln(Fa) and associated variance estimate are calculated separately for each age over a range of years specified by the user. The user may specify a "Minimum CV of the mean"; if the estimated CV of the mean falls below the corresponding value it will be overwritten.

(6) The weighting factor θ is calculated as :

$$\theta_a = \frac{var(\overline{\ln(F_a)})}{var(\ln(FS_y) + \ln(S_a)) + var(\overline{\ln(F_a)})} \quad (21)$$

(7) Variances and covariances of $FS_y$ and $S_a$ are available from the model fit. The variance of $FS_y.S_a$ is obtained by simple linear approximation as described in section 2.2.5.

The shrunk VPA is therefore a conventional VPA generated with F in the last year at each age estimated from:

$$\ln(F_{a,y}) = ( 1 - \theta_a ) \ln(\bar{F}_a) + \theta_a . \ln(FS_y . S_a) \quad (22)$$

F on the last true age in the shrunk conventional VPA are found by assuming that the selection pattern conforms to the estimated $S_a$ from the model fit, and iterating the VPA 20 times, with the F in the last year obviously being unchanged.

### *2.2.3 ICAVIEW.EXE: Graphical display of results*

This programme displays a number of summary and diagnostic graphs on the screen, which can be written to a printer if necessary. The quantities plotted in the graphs are described below.

a) An overall tuning diagnostic graph. This is a plot of the index SSQ against the F at reference age from a separable VPA. The index SSQ are calculated as:

AGED SURVEY

$$\sum_{a,y} (\ln(I_{a,y}) - \ln(\hat{I}_{a,y}))^2$$

SSB SURVEY (23)

$$\sum_{y} (\ln(I_{y}) - \ln(\hat{I}_{y}))^2$$

where the predicted index values are related to the population sizes as in Eqns 5 and 6.

The "total SSQ" is simply calculated as the sum of the SSQs for all the indices. Note that these are sums of squares of unweighted residuals.

b) A stock summary screen. Yield, fishing mortality, recruitment and spawning stock biomass are graphed together on a single screen. These quantities are:

i) Yield. Simply the information held in the "landings" input file.

ii) Fishing mortality. For the years over which a separable model has been fitted, the mortality graphed is the fishing mortality at reference age, ± the standard deviation of this parameter estimate (if available from ICA2). For earlier years, the quantity graphed is:

$$\frac{1}{\text{Number of ages}} \sum_{a} \frac{F_a}{S_a} \quad (24)$$

iii) Recruitment. For the years over which the separable model was fitted, the recruitments plotted are the population sizes at the earliest age estimated from the analysis. For earlier years, the recruitments are the population sizes at the earliest age calculated by conventional VPA within the model.

iv) Stock sizes. Two estimates of stock size are plotted. One is simply the total stock biomass at 1 January, as

$$\sum_{a} N_a W_a \quad (25)$$

The other is an estimate of spawning stock size at spawning time, as:

$$\sum_{a} N_{a,y} W_{a,y} O_a e^{-F_{a,y}PF - M_{a,y}PM} \quad (26)$$

c) The quantities displayed in the separable model diagnostics screen are:

i) Separable model residuals, as $\ln(C) - \ln(\hat{C})$, where C are the observed catches and the $\hat{C}$ are the expected catches predicted from the separable analysis.

ii) Estimates of selection at age, ± standard deviations. Note that selection at the reference age is fixed (=1) and the selection on the last age is selected by the user at run-time. Selection on the plus-group is assumed equal to the selection on the last true age. These three points are not therefore parameter estimates and do not have associated estimates of standard errors.

iii/iv) Year and age marginal totals. These quantities are respectively

$$\sum_{a} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y})) \quad (27)$$

and

$$\sum_{y} (\ln(C_{a,y}) - \ln(\hat{C}_{a,y})) \quad (28)$$

d) For each index series, the four diagnostic plots display:

i) Stock size and index predictions. The continuous line in the graph in the top-left corner is a plot of either spawning stock biomass at the time of spawning (see above) in the case of an SSB index, or in the case of an age structured index the quantity plotted is the estimated population size at age at the time of the survey, as:

$$N_{a,y}.\exp(-F_{a,y}-M_{a,y})PZ_A \qquad (29)$$

Using the linear catchability model for an SSB index as an example, the plotted triangles in the graph are stock sizes estimated from each index observation:

$$\frac{I_{y,B}}{\hat{Q}_B} \qquad (30)$$

Age-structured indices are treated similarly, except that the population size at the time of the survey should be substituted for SSB in the foregoing. Equations corresponding to the other catchability models are used in this diagnostic plot when the other catchability models are chosen.

The two lower graphs on this screen are plots of

$\ln(I_{y,B}) - \ln(Q_B.SSB_y)$ against $\ln(Q_B.SSB_y)$;

and of

$\ln(I_{y,B}) - \ln(Q_B.SSB_y)$

against time, for indices of spawning stock size; for age structured indices the quantities are

$\ln(I_{a,y,A}) - \ln(Q_{a,A}N_{a,y,A}.\exp(-(F_{a,y}+M_{a,y}).PZ_A))$

against

$\ln(Q_{a,A}N_{a,y,A}.\exp(-(F_{a,y}+M_{a,y}).PZ_A))$

and of

$\ln(I_{a,y,A}) - \ln(Q_{a,A}N_{a,y,A}.\exp(-(F_{a,y}+M_{a,y}).PZ_A))$

against time.

### 2.2.4 VIEWSRR.EXE: Graphical display of stock-recruit model fit

The fitted line representing the stock-recruit relationship is the line

$$R = \frac{a\ SSB}{b + SSB}\ \exp(\sigma^2_{srr}/2) \qquad (31)$$

Residual plots as described above are also drawn.

### 2.2.5 ICPROJ.EXE: Stock projection with variance estimates

The ICPROJ programme has been provided here as one of a number of possible approaches to the problem of estimating the uncertainties associated with calculations of stock size in future years. Here stock sizes in succeeding years are calculated in a deterministic way from the terminal populations of the stock assessment, and the specified fishing mortality multipliers and fleet catch ratios at age. Estimates of the variance-covariance matrix are then used to assess the uncertainty about the deterministic path by the delta-method.

Stock projections are calculated in the usual way. Given a starting population size $N_{a,y+1}$ (where y= last year of data), then $F_{y+1,age}$ and the corresponding populations and catches are given by

$$\text{Fleet } F_{a,y+1,f} = \text{Fmult}_{f,y+1}FS_yS_aCR_{a,f}$$
$$F_{y+1,a} = \sum_f \text{Fleet } F_{a,y+1} \qquad (32)$$

In subsequent years, say for year y+2,

$$N_{a+1,y+2} = N_{a,y+1}\exp(-F_{a,y+1}-M_{a,y})$$
$$\text{Fleet Catch}_{y,f} = \qquad (33)$$
$$\sum_a \left( \frac{\text{Fleet } F_{a,y+1,f}}{F_{a,y+1}+M_{a,y+1}}.N_{y+1,a}(1-\exp(-F_{a,y+1}-M_{a,y+1}))W_{a,y+1} \right)$$

If an estimate of recruitment for year y+1 is available as a parameter from the model fit, it is used directly. If not, and in any case for subsequent years, recruitment is estimated from the Beverton and Holt stock-recruit relationship. For parameter estimates a and b and stock size SSB corresponding to year i, then mean recruitment is given by

$$R_{y+lag} = \frac{a.\hat{SSB}_y}{b+\hat{SSB}_y}\ \exp\ (\sigma^2_{srr}/2) \qquad (34)$$

SSB is calculated as in Eqn 4; a and b are parameter estimates derived by the ICA2 procedure, $\sigma^2_{srr}$ is the variance about the stock-recruit relationship.

Now consider the calculation of SSB in projections as a function $SSB_y = f(X)$, where X is vector of parameters comprising the $N_{a,y}$, estimates of $S_a$, a and b of the stock-recruit relation, recruits in year y+1 if available, and $F_y$. Assume the remaining parameters (Natural mortality M, spawning ogive O, catch ratios CR, mean weights W, etc., are estimated with negligible variance. The variance-covariance matrix of X is a subset of the parameter variance-covariance matrix estimated in the ICA2 procedure. Estimates of the variances of the projected SSBs may then be calculated using the delta method,

$$\mathrm{Var}(\hat{SSB}_y) = \sum_{i=1}^{i=j} \left( \frac{d\hat{SSB}_y}{dX_i} \right)^2 \mathrm{Var}(X_i) + 2\sum_{i=1}^{i=j-1} \sum_{k=1}^{k=i} \frac{d\hat{SSB}_y}{dX_i} \frac{d\hat{SSB}_y}{dX_k} \mathrm{CoVar}(X_i X_k) \quad (35)$$

Variances of the catch by fleet may be calculated in an exactly analogous manner. The $dX_i/dSSB$ and $dX_i/d(\text{Fleet Catch})$ are estimated numerically. Risk is calculated by assuming SSB is normally distributed.

### 2.2.6 *VIEWPRO.EXE: Display results of projections*

The programme displays the stock biomasses for the years over which the projections have been calculated, together with the estimated probability that in any given year the stock size will fall below the specified biologically-allowable minimum (MBAL). In addition the projected catches by fleet are plotted.

The first screen displays in its upper half the projected spawning stock with 95% confidence limits drawn as error bars, together with the specified MBAL. The lower part of this screen displays the estimated probability that the stock size would fall below MBAL in forthcoming years.

Stock size is calculated from Eqn 4 applied to population abundances N estimated in projections by the method of Eqns 32 and 33. 95% confidence limits are estimated conventionally using the variance estimates calculated from Eqn 35.

Subsequent screens display the estimated catches by fleet with 95% confidence limits drawn as error bars.

## 2.3 *Missing values*

### 2.3.1 *Missing values in the survey indices*

Missing observations in either the age-structured or the spawning biomass survey indices can be flagged by setting them to any negative value. These values will then simply be ignored in all the calculations.

### 2.3.2 *Missing values in the catches at age*

If any of the catch at age observations are zero or negative in the range of years and ages over which the separable model is to be fitted, then they will be treated as missing values and will be ignored in the separable model fit. In the conventional VPA used to generate starting values for the separable model, two treatments are possible:

(1) If the value is zero and at the last true age, the lowest observation in the catch at age matrix is used in the VPA calculation.

(2) If the value is zero but not at the last true age (ie it lies within the cohort), the observation is ignored and F at this year and age is approximated by calculating its expected value on the assumption that the pattern of F across ages is similar to that in other years

(3) If the value is negative, the absolute value is used in the VPA calculations. This choice allows the user to insert guessed values to initiate a conventional VPA, but the subsequent model fit will ignore the observations. This option is useful where an entire years' catch at age observations may be missing.

## 3.0 References

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FOLD OUT FOR VARIABLE LIST

## Appendix: Index to Variables

Suffices and indexing variables

a,y suffices indicate age and year throughout.

A suffix indicates the Ath age-structured survey index

B suffix indicates the Bth survey index of spawning stock biomass

j,k suffices index parameters in the vector of parameter estimates calculated in the model fit and subsequently used to initiate the projections

f suffix indicates the fth fleet in the projections

Parameters and data

a, b = parameters of the Beverton and Holt stock-recruit relationship.

$C_{a,y}$ = catch in numbers

C hat $_{a,y}$ = catch in numbers predicted from model

$CR_{a,f}$ = ratio of the catch in number at age a by fleet f to the total catch in number by all fleets, in the last year for which there are catch at age data.

$df_C$ = degrees of freedom for the separable model

$df_B$ = degrees of freedom for the Bth biomass index

$df_A$ = degrees of freedom for the Ath age-structured index

$F_{a,y}$ = fishing mortality at age and year

$Fmult_{f,y}$ = proportionate change in the fishing mortality exerted by fleet f in year y, relative to the mortality exerted by that fleet in the last year for which there are catch-at-age data.

$FS_y$ = reference fishing mortality for the separable model, by year.

$g_B()$ = catchability model for the Bth index of spawning biomass

$h_A()$ = catchability model for the Ath index of spawning biomass

$I_y$ = index observations

I hat $_y$ = model predictions of index observations

$K_B$ = parameter describing deviation of the catchability relationship of the Bth SSB index from linearity

$K_A$ = parameter describing deviation of the catchability relationship of the Ath SSB index from linearity

$k_A$ = number of ages in the Ath age-structured index

lag = the number of calendar years between spawning and recruitment

$M_{a,y}$ = natural mortality at age and year

$N_{a,y}$ = numbers of fish alive in the sea on 1 January, at year and age.

$O_{a,y}$ = proportion of fish spawning at age and year

PF,PM = proportions of F and M that occur before spawning

$PZ_A$ = proportion of total mortality incurred between 1 January and the time of the Ath survey

$Q_B$ = catchability of the Bth index of spawning biomass

$Q_{a,A}$ = catchability of the Ath age-structured index at age

$R_y$ = numbers of recruiting fish on 1 January of each year, at the first age in the catch-at-age matrix.

$S_a$ = selection at age

SSB hat $_y$ = spawning stock biomass at year from fitted populations

$W_{a,y}$ = weight at age at spawning time at age and year

$\lambda_{a,y,C}$= relative weight to be given to the catch at age observation at age a in year y.

$\lambda_{B}$ = weight to be given to the Bth SSB index relative to the catches at age.

$\lambda_{a,A}$ = weight to be given to the Ath age-structured index at age a relative to the catches at age

$\lambda_{srr}$ = weight to be given to the stock-recruit relationship

$\alpha$ = extent to which the errors in the age-structured index are correlated across the ages

## *Section C. Programmer's Reference*

# 1.0 Introduction

## *1.1 Background*

This text documents the Integrated Catch at Age programmes (Version 1.2). These programmes form an implementation of least-squares integrated statistical catch-at-age analysis. The present documentation complements the User Guide and the Technical Reference. The purpose of this document is to enable programmers to modify the source code as required, and to enable them to implement such modifications as may be necessary to install the routines on systems other than MSDOS.

The approach to the documentation taken here has been to provide an overview of the system functions, programme structures and file structures. Detailed documentation of the code has not been included here, but has rather been included as extensive comments in the source code.

Three analytic programmes are documented here:

ICA1 - Data reading, estimation of starting parameters and index divergence diagnostics;

ICA2 - Model minimisation and estimation of variance-covariance matrix;

ICPROJ - Multifleet stock projection with variance estimates and calculation of risk.

Source code for three graphics routines is also provided:

ICAVIEW - Stock summary and residual plots.

VIEWSRR - View stock-recruit relationship and residual plots

VIEWPRO - View stock projections.

## *1.2 Language and version*

The ICA1 and ICA2 programmes are written in Microsoft FORTRAN Version 5.1. They require linking to the Numerical Algorithms Group (NAG) FORTRAN workstation library (Release 1) (Anon., 1989). Routines BRENT, GAMMQ, GSER and GCF are as given by Press *et al.* (1989)..

Language-intrinsic routines used are:

SCAN : a function to search a string variable;

ALLOCATE and DEALLOCATE to define run-time memory;

GETTIM and GETDAT : return system time and date

Some use is also made of Microsoft FORTRAN file access error codes.

The ICAVIEW, VIEWSRR and VIEWPRO programmes are written in Borland Turbo PASCAL Version 5.0. They require linking at run-time to the XYPlotW and ContourW graphics object libraries written by M.V. Bravington, Renewable Resources Assessment Group, Imperial College of Science and Technology, London.

## *1.3 A note on array indexing*

Different parts of the data set may begin and end at different years or ages, and in addition the separable model will probably be fitted only over a restricted part of the catch-at-age data. The following convention has been used when storing and accessing these data:

- The first years' datum for the catch at age, the SSB surveys and the aged surveys is stored in the first location of each of the arrays. For example, if catch data are from 1975 to 1990 and from ages 1 to 10, and aged survey data are from 1980 to 1989 and ages 3 to 7, then CN(1,1) stores the catch at age in 1975 at age 1, and Aindex(index, 1, 1) stores the survey index in 1980 at age 3, and similarly for the other types of data.
- In most cases and except where it is obvious, do loop indexing variables run in true years, eg from 1975 to 1990, and are dereferenced to the start of the array. Hence a loop to access both catch and survey data in the above example would look like this:

```
do year = 1980, 1989
    CN(year-firstyear+1, ...) = ...
    Aindex(index,year-fyear(index)+1, ...) =
enddo
```

where firstyear is the first year of catch at age data and fyear(index) is the first year of the survey index. The age range is dealt with in a similar fashion. Although slightly inefficient and cumbersome this approach makes the code a little more legible.

### *1.4 A note on common blocks*

Contrary to conventional FORTRAN usage, most of the data and parameters are stored and passed in common blocks except where there is a clear requirement to do otherwise. This avoids the use of confusingly long parameter lists when calling routines, and is more akin to object-orientated programming methods.

## 2.0 Function Summary

The functioning of the ICA1 programme is described below in pseudocode. The names of the main routines implementing each step are given in parentheses.

```
Read in data files (READER, READSBIX,
READAGIX)
Accept run-time choices from the user          (PARMSET)
Ask user for lowest and highest likely F
From lowest to highest F, in 20 intervals, do
    Calculate a separable VPA by Pope &
    Shepherd (1982) method                     (SEPVPA)
    Calculate a conventional VPA initiated
    from separable VPA                         (CONVPA, CVPA)
    Fit the catchability relationships         (CONVPA)
    Calculate the sum of squared residuals
    (SSQ) for each index, write these to
    a file (ICADIAG.OUT)
    Remember at which F the total SSQ is
    lowest, =Flow
End do

Start from Flow
While (F is not at minimum SSQ) do             (BRENT)
    Calculate a separable VPA by Pope &
    Shepherd (1982) method                     (SEPRES)
    Fit the catchability relationships         (CONVPA, CVPA)
    Calculate the sum of squared residuals
    (SSQ) for all the tuning series
    Calculate a new F for best fit to the indices
End do

From the VPA so obtained, calculate
starting estimates for all parameters          (CONVPA)
Create all the output files                    (TABLEOUT,
                                               WRITEBLK,
                                               LSFUN1)
STOP
```

The ICA2 programme function is summarised as:

```
Read the data and parameters estimated
in ICA1                                        (READBLOCK)
Prompt the user for reweighting options,
F tolerance and age-structured index internal
correlations.
REPEAT UNTIL F CONVERGENCE
CRITERION IS MET
    IF not the first run then
    REPEAT UNTIL SSQ CONVERGENCE
    CRITERION IS MET
        Fit the Separable model over the
        specified number of last years of the
        data set, and fit the indices over all years
        Recalculate the conventional VPA       (NAG E04FDF)
        based on the separable model fit       (LSFUN1)
    ITERATE
    Calculate Variance-Covariance matrix
    estimates                                  (NAG E04YCF)
    ENDIF
    Write the Var-CoVar Matrix to file         (WRITEVCV)
    Calculate residuals about the model fit    (MAIN,
                                               UNWTDSSQ)
    Display the Analysis of Variance table     (DISPLAYWTS)
    Recalculate the weights according to the
    user's choice
ITERATE
Calculate variances etc                        (CALCSTATS)
Write out results                              (TABLEOUT)
Write out the stock-recruit file               (WRITESRRFILE)
Calculate and write out shrunk VPA if required (SHRINKF)
Write the data and new parameter estimates
to disk                                        (WRITEBLOCK)
STOP
```

Lastly, the ICPROJ summary:

```
Read the data and parameters estimated
in ICA2                                        (READBLOCK)
Read the Variance-Covariance matrix            (READVCV)
Read the data for the projections              (READPROJFILE)
Check the given catch ratios are correct       (CHKCATRATIO)
Calculate mean Wt, M, maturity for projection  (SETPROJVARS)
Calculate a baseline projection                (PROJECT)
Get the minimum acceptable stock size          (READMBAL)
Write baseline projection to detailed output file
Calculate derivative matrix                    (CALCDEVS)
Calculate variances of catch and stock by
delta method
Write estimates of catch and stock with
associated variances & risk to file
Write the derivative matrix to file
STOP
```

## 3.0 Convergence Testing

As a simple test of the convergence of the algorithm using the data and model specified in Appendix 2, the ICA2 programme was restarted 20 times from a randomised starting point based on the initialising position estimated by the ICA1 method. The new starting positions were formed by:

$$X' = X * ( 1 + \mathbf{N})$$

where **N** is a random variate with uniform

distribution from -0.2 to +0.2, and X is the starting vector estimated in the ICA1 method. This trial indicated that fishing mortality on reference age converged reliably to within 0.04%. Further testing is documented in Appendix 1 to Anon. (1994).

## 4.0 Files Written by the Programmes

### *4.1 ICA.OUT*

This file is the principal output file from the system. It contains:

a) Input estimates of catches of numbers of fish at age and year.

b) Input estimates of fish abundances from surveys of spawning stock biomass.

c) Input estimates of fish abundances from age-structured surveys.

d) Estimates of population abundance by year and age.

e) Estimates of fishing mortality by year and age.

f) A summary of stock estimates: landings, total and spawning stock sizes, arithmetic mean fishing mortality over a specified age-range, and yield per spawning stock biomass ratio.

g) A list of parameter estimates ± one standard deviation (on log scale).

h) Summaries of the distributions of residuals about different parts of the model.

The file is generated by the routine TABLEOUT in unit READER.

### *4.2 ICA.VIE*

This file contains essentially the same information as ICA.OUT, but whereas the former file is laid out in a suitable manner for inclusion in a report or working document, ICA.VIE is designed for the transfer of data from one programme to another. More particularly it is designed to pass data from ICA1 or ICA2 to ICAVIEW, although it could equally be used to pass information to spreadsheets.

The file is generated by the routine TABLEOUT in unit READER.

### *4.3 ICA.RES*

Contains a list of the observed and expected values for each of the observations used to fit the model, in the order:

| | | |
|---|---|---|
| year | age Observed Catch in Number (termination code -99) | Expected catch in number |
| index | year Observed SSB survey datum (termination code -99) | Expected SSB survey datum |
| index | year age Observed aged survey datum (termination code -99) | Expected aged survey datum |

The file is written by the LSFUN1 routine when it is called with WRITEOUT set = .TRUE. It is read by ICAVIEW and also by the routine CALCSTATS (called by ICA2 and TABLEOUT).

### *4.4 ICA.SRR*

Contains a list of pseudo-observed and expected stock and recruit values, as used for fitting the stock-recruit relation.

The file is written by WRITESRRFILE

### *4.5 ICADIAG.OUT*

Contains estimates of the sums of squared residuals of the surveys compared with conventional VPA populations initiated with separable VPA, for 20 values of reference F over the range specified by the user.

The file is written by ICA1.

### *4.6 ICA.AV*

Contains information about the analysis of variance about the model fit.

File written by ICA2.

### *4.7 ICA.VC*

Contains (1) The parameter covariance matrix, and (2) the parameter correlation matrix.

File written by ICA2. It is read by READVCV

### *4.8 ICA.TMP*

Contains all data and parameters; used to pass information between ICA1 and ICA2 and between ICA2 and ICPROJ.

File written by ICA1 and ICA2, and read by ICA2 and ICPROJ; ICA2 overwrites the file after completing a run.

### *4.9 PROJECT.POP*

Contains details of the baseline projection: stock sizes, partial F by fleet, catch in numbers by fleet and catch in weight by fleet.

File written by ICPROJ.

### *4.10 ICA.PRO*

Contains the SSB and catch by fleet and by year, with associated estimates of variance and the risk that the SSB will fall below MBAL.

File written by ICPROJ.

### *4.11 DERIVS.TST*

Contains the matrix of derivatives : d(Stock size in projections)/d(ICA parameter estimate).

File written by ICPROJ.

### *4.12 ICA.SHR*

If the user has chosen to generate a shrunk VPA it is written to this file. The model fit is left unchanged and is written to ICA.OUT as before. The file holds shrinkage diagnostics, fitted populations and a stock summary table.

The file is written by SHRINKF.

## 5.0 Compilation

The FORTRAN analytic programmes may be compiled for either MS-DOS or WINDOWS. Compilation under MS-DOS will result in programmes that run faster, but the ICA2 programme compiled under DOS will be limited to analysing rather small data sets. Compilation under WINDOWS incurs speed disadvantages but will allow any additional memory installed to be used. Batch files for compiling under WINDOWS and under DOS are given together with the source code.

## 6.0 Index of Subroutines

| ROUTINE | UNIT | DESCRIPTION |
|---|---|---|
| APPROXSRR | SRR.FOR | Approximate estimates of Bev-Holt SRR |
| BRENT | ICA1.FOR | One-dimensional root finding |
| CALCSTATS | STATS.FOR | Calculates variances etc. |
| CALCDEVS | ICPROJ.FOR | Calculate matrix of derivatives for projections |
| CHKCATRATIO | ICPROJ.FOR | Checks catch ratios given in projection file |
| CONVPA | CONVPA.FOR | Runs VPA, fits surveys and calculates variances |
| CVPA | CVPA1.FOR | VPA calculation initiated with separable VPA |
| CVPA2 | CVPA1.FOR | VPA calculation initiated with objective function |
| DISPLAYWTS | ICA2.FOR | Display weights assigned to the indices on screen |
| E04FDF | NAG LIBRARY | Quasi-Newton Nonlinear estimation |
| E04YCF | NAG LIBRARY | Estimates variance-covariance matrix |
| GAMMLN | STATS.FOR | Runs incomplete gamma function(*) |
| GAMMQ | STATS.FOR | Runs incomplete gamma function(*) |
| GCF | STATS.FOR | Runs incomplete gamma function (c.f.) (*) |
| GETSRR | SRR.FOR | Extracts stock & recruits from VPA |
| GSER | STATS.FOR | Runs incomplete gamma function (series) (*) |
| HELLO | ICA2.FOR | Displays start-up message |
| ICA1 | ICA1.FOR | Data reading and initialisation |
| ICA2 | ICA2.FOR | Fitting full separable model |
| ICPROJ | ICPROJ.FOR | Multifleet projection with variance estimates |
| IOCHECK | READER.FOR | Checks whether a file exists |
| LSFUNI | OBJECT.FOR | Objective function |
| PARMSET | PARMSET.FOR | Reads run-time options from user at screen |
| REPORT | ICA2.FOR | Display E04FDF NAG error number and message on screen |
| READAGIX | READER.FOR | Reads age-structured indices |
| READBLOCK | READER.FOR | Reads temporary file (ICA.TMP) to common blocks |
| READER | READER.FOR | Reads catch and catch sampling data |
| READMBAL | ICPROJ.FOR | Reads the MBAL from screen |
| READPROJFILE | ICPROJ.FOR | Reads projection file |
| READSBIX | READER.FOR | Reads indices of spawning biomass |
| READSRRDAT | SRR.FOR | Reads historic stock & recruit estimates |
| READVCV | ICPROJ.FOR | Reads variance-covariance matrix from ICA.VC |
| SEPVPA | SEPVPA.FOR | Does Pope & Shepherd separable VPA |
| SETPROJVARS | ICPROJ.FOR | Calculates M, ogive & wts for projections |
| SHRINKF | SHRINK.FOR | Generates VPA with F shrinkage based on mode lfit |
| TABLEOUT | READER.FOR | Generates output files: (ICA.OUT and ICA.VIE) |
| WRITEBLOCK | WRITEBLK.FOR | Writes the common blocks to disk (ICA.TMP) |
| WRITESRRFILE | SRR.FOR | Writes stock and recruit estimates to file |
| WRITEVCV | ICA2.FOR | Write the variance-covariance matrix to file |

## 7.0 Index of Functions

| FUNCTION | UNIT | DESCRIPTION |
|---|---|---|
| BRENT | ICA1.FOR | One-dimensional minimisation |
| CALCSSB | PARMSET.FOR | Calculate spawning stock biomass from fitted Ns |
| CALCPROSSB | ICPROJ.FOR | Calculate SSB from populations in projections |
| CALCRECRUIT | ICPROJ.FOR | Calculate recruitment from SSB and SRR |
| COHORT | PARMSET.FOR | Pope's cohort approximation |
| GAMMQ | STATS.FOR | Incomplete gamma function |
| GAMMLN | STATS.FOR | returns ln(gamma(X)) |

| | | |
|---|---|---|
| MISSING | SEPVPA.FOR | Treatment of missing and zero values |
| REFINE | PARMSET.FOR | Calculates F, N to specified precision for VPA |
| SEPRES | ICA1.FOR | Runs Separable VPA and calculates residuals against indices |

## 8.0 Index of Common Blocks

| | |
|---|---|
| Indat.inc | Input data |
| SepModel.inc | Model parameters and options |
| stats.inc | Variances, number of observations, etc. |
| srr.inc | Data and parameters used for estimating stock-recruit relation |
| proj.inc | Populations and data for projections |

## 9.0 PASCAL Programmes

Copies of the source code for the graphics viewing programmes VIEWSRR, VIEWPRO and ICAVIEW are provided. ICAVIEW reads the files ICADIAG.OUT, ICA.VIE and ICA.RES. It produces a series of "tableaux", each containing four graphs. The first graphs display general parameters of the stock assessment and the remaining ones display residual plots for each tuning index.

VIEWSRR is a short programme which reads the fitted parameters and pseudo-observations for the stock-recruit relation, and draws three graphs from these.

VIEWPRO displays the projected stock size with error bars, and risk of the stock size declining below the specified minimum level. Next the projected catches by fleet (with error bars) are displayed.

## 10.0 Structure Diagrams

Structure diagrams for the ICA1, ICA2 and ICPROJ programmes are given in Figures 10.1 – 10.3.

## 11.0 References

**Anonymous.** 1989. Handbook for the NAG FORTRAN workstation library. Published by NAG Ltd, Wilkinson House, Jordan Hill Road, Oxford, United Kingdom.

**Anonymous.** 1994. Report of the Herring Working Group for the Area South of 62_N. ICES CM 1994/Assess:13.

**Pope, J.G. and Shepherd, J.G.** 1982. A simple method for the consistent interpretation of catch at age data. *Journal du Conseil Insternational pour l'Exploration de la* Mer, **40**, 176—184.

**Press, W.H., Flannery, B.P., Teukolsky, S.A. and Vetterling, W.T.** 1989. Numerical Recipes. Cambridge University Press, 702pp.

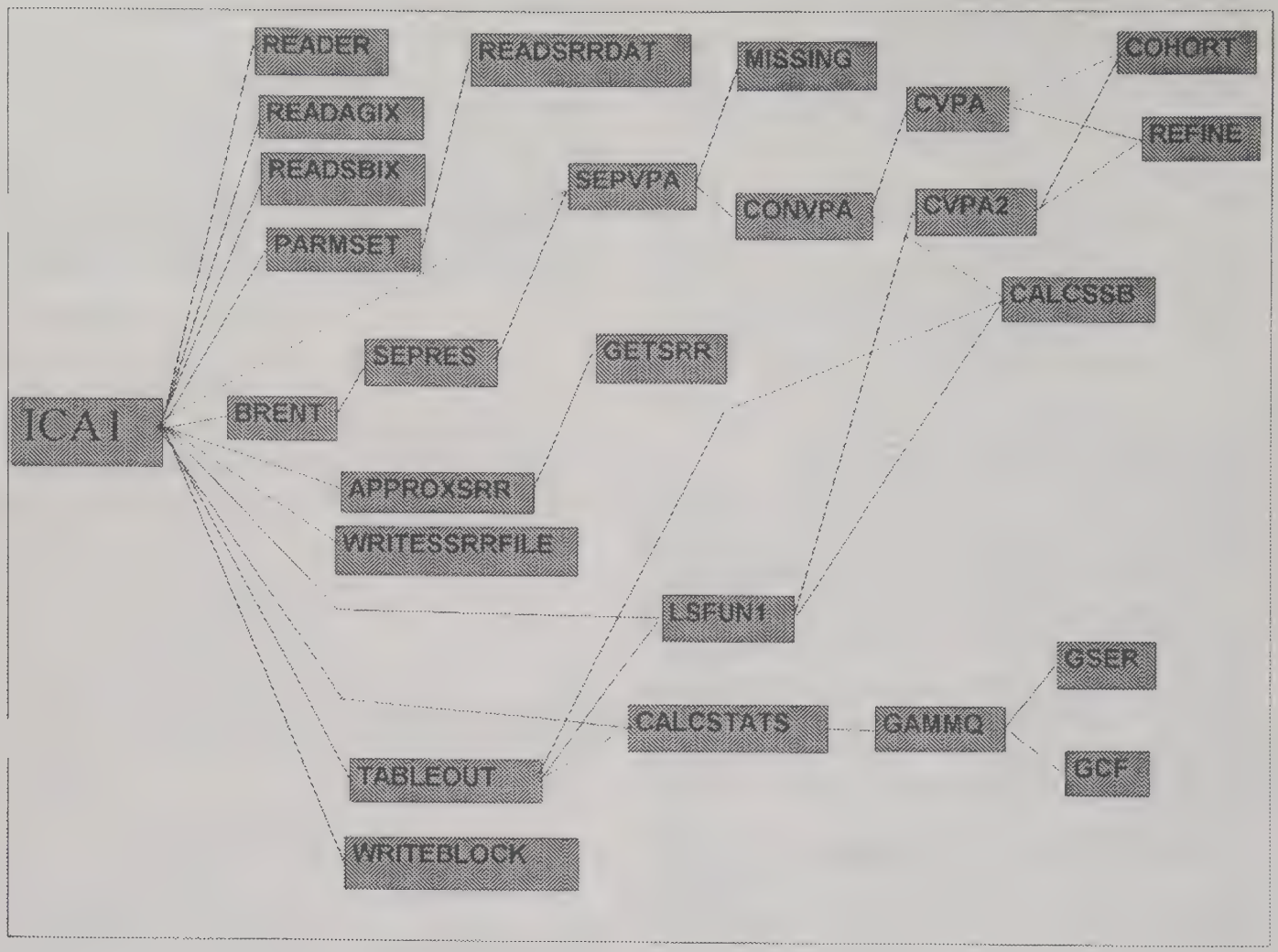


Figure 10.1 Structure diagram for the ICA1 programme

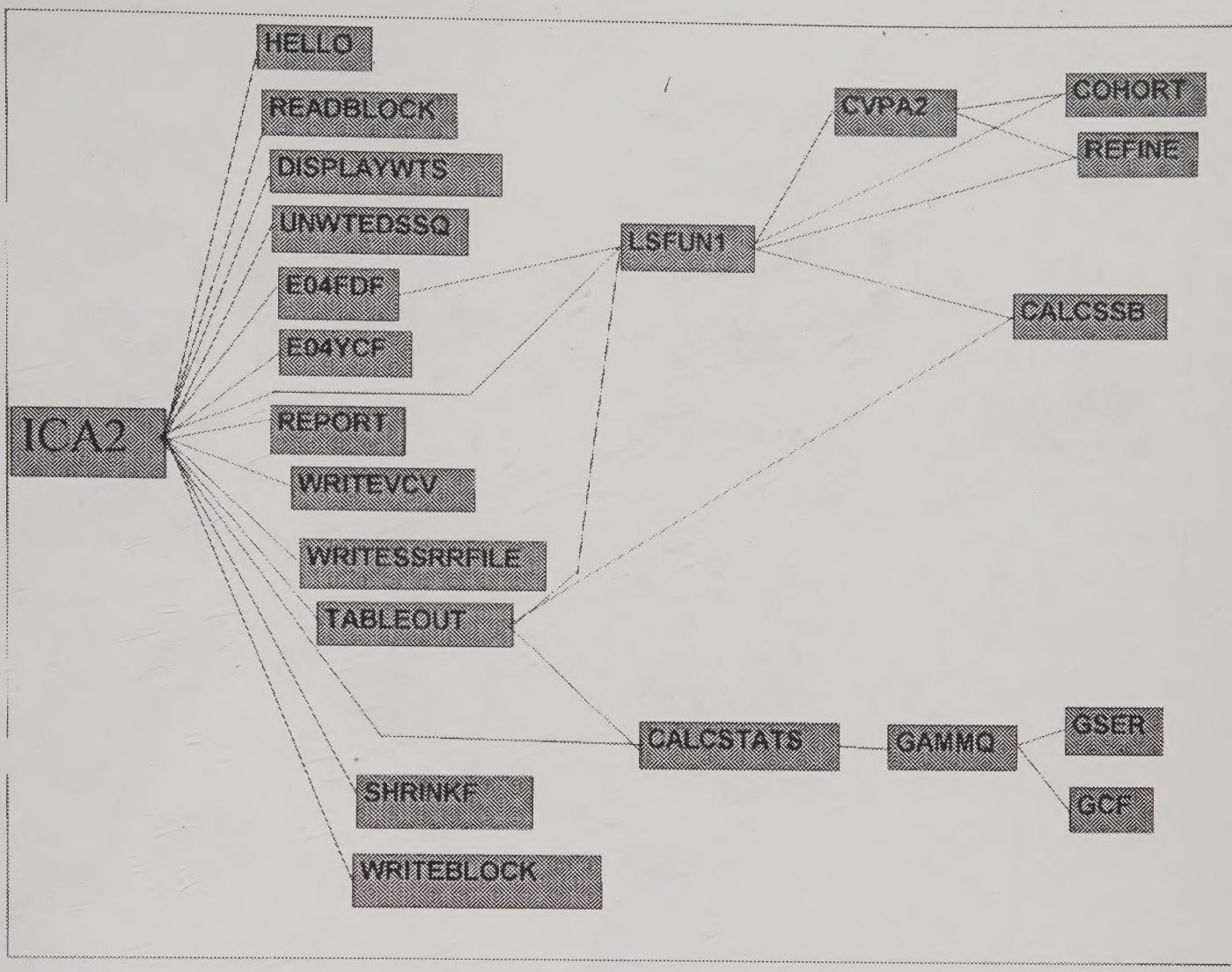


Figure 10.2 Structure diagram for the ICA2 programme

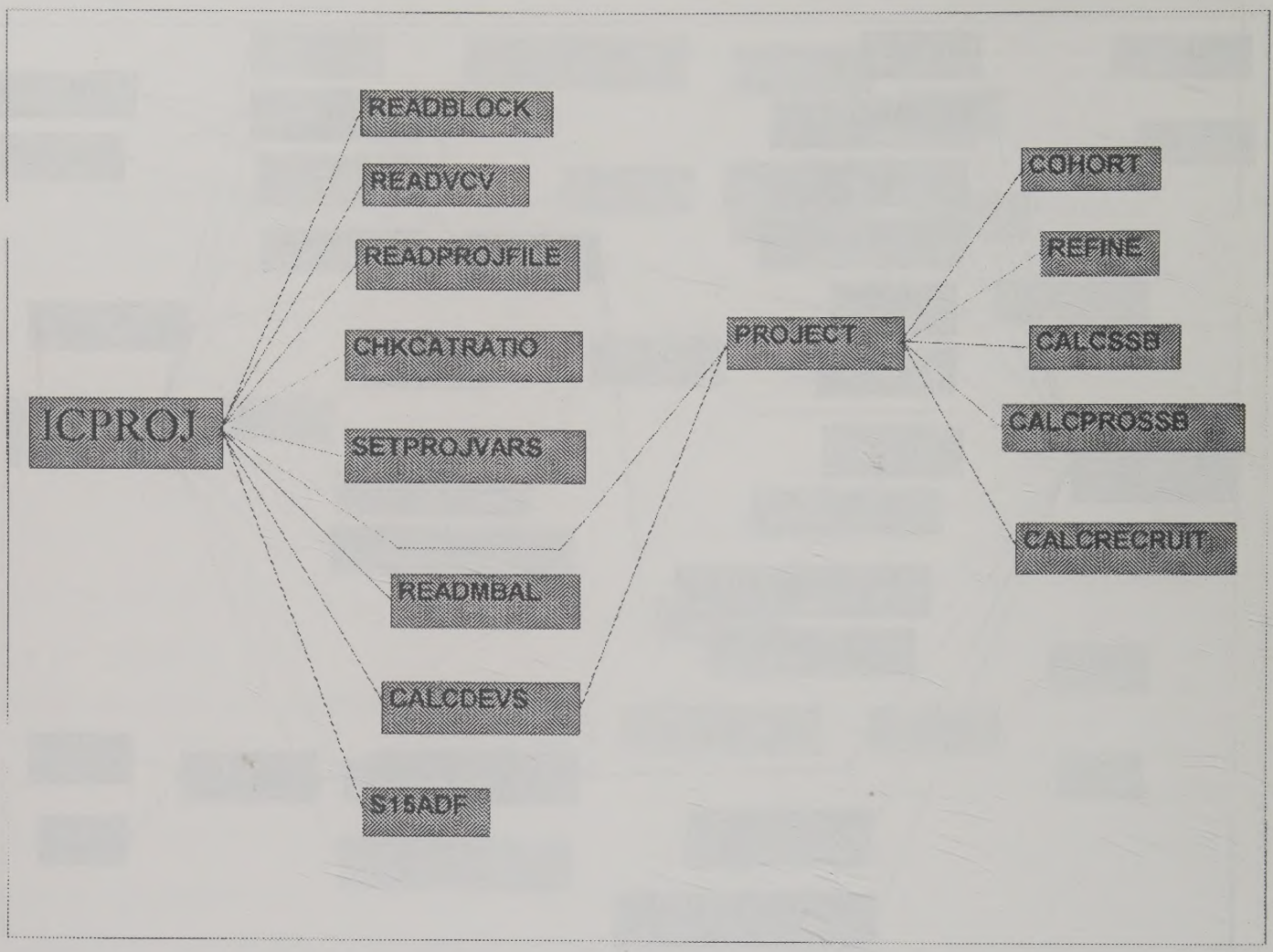


Figure 10.3 Structure diagram for the ICPROJ programme



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1984 **No.31** A Selected Review of Hydrodynamic Force Coefficient Data on Stranded Wires Used in Fishing Gear.
By R.S.T. Ferro and E.H. Hou, 20pp.

1985 **No.32** Small Mesh Cod-end Covers.
By P.A.M. Stewart and J.H.B. Robertson, 11pp.

**No.33** Attachments to Cod-ends.
By P.A.M. Stewart and J.H.B. Robertson, 15pp.

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By J.H.B. Robertson and R.S.T. Ferro, 11pp.

1989 **No.40** The Movements and Spawning Behaviour of Adult Salmon in the Girnock Burn, a Tributary of the Aberdeenshire Dee, 1986.
By J. Webb and A.D. Hawkins, 42pp.

**No.41** The Movements of Adult Salmon within the River Spey.
By R. Laughton, 19pp.

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